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THE MOVEMENTS OF OIL AND GAS THROUGH ROCKS.[1]

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One of the most interesting problems confronting the student of oil geology is the migration of oil and its possible causes. That such migration is quite prevalent, and perhaps a universal characteristic of all oil, is scarcely to be doubted. The widespread occurrence of oil and gas seeps and springs, and of occasional gushers and flowing wells, bears mute evidence of the truth of this fact. The explanation of the "why" and the "wherefore" of migration is by no means simple. There are a great many possible causes of migration, each one of which has had its influence. These depend upon local conditions and, hence, may be more or less pronounced or may vary in intensity and importance from field to field. For this reason we find a lack of agreement among geologists as to the relative importance of these various causes. Each one champions, as is natural, the particular cause most active in the fields under his direct observation. The writer has attempted to summarize the divergent views expressed in the all too meager literature on this subject, and to differentiate as far as possible the effects of each active factor.

[1] The figures in the text refer to articles in the appended partial bibliography, which deal either directly or indirectly with the features discussed.

The problems of oil movements are intimately connected with the problems of its origin. While there is as yet no general agreement among geologists on the question of oil origin, the organic theories may be considered to be at least tentatively established. It is outside of the scope of this paper to discuss such theories. The writer personally feels convinced that oil is derived from organic material, such as plant and animal remains which are buried in the finer sediments, the muds, clays, and oozes at the time of their deposition. Because of the fine and, hence, dense character of these sediments, of the presence of salt water, of generally undisturbed and quiet conditions at the place of deposition, the organic remains were protected from rapid decomposition, and suffered only a sort of selective putrefaction. Upon deeper burial by the increasing load of sediments, there took place decomposition and distillation of the organic remains which resulted in the formation of oil. This change was in part due simply to the increasing pressure and temperature, and in part due to the action of bacteria. Thus, the first fundamental premise of this paper is:

All important oil accumulations are the result of the chemical or bacterial alteration of organic remains.

In probably 95 per cent. of all oil pools, sands and sandstones form the reservoir rocks. They are the oil producers but not the oil formers. The writer is convinced that oil is not indigenous to the great majority of oil sands. The coarse character of most oil sands, their original porosity, the disturbed conditions at the site of their deposition as proved by their cross-bedding and by their lenticular streaking with gravel and the virtual absence of fossils, all prove that sands are unsuitable for the preservation of perishable organic remains. This is further borne out by the absence of important commercial accumulations of oil or gas in the very thick sandstone and conglomerate series, as well as the absence of oil in certain sandstones that are characterized by an abundance of fossils, such as brachiopod and mollusc casts. Thus, the second fundamental premise of this paper is:

By far the greater part of oil is formed in the fine-grained sediments, those that ultimately form shales and, to a lesser extent, limestones.

If we grant the truth of these two fundamental premises, the questions concerning the movements or flow of oil and gas through rocks can be clearly differentiated into two separate problems. Thus, it becomes necessary to answer the following two questions:

First, what causes the removal of oil and gas from the oil-forming shale, and its segregation in the sands and sandstones?

Second, what causes the oil that is disseminated through the sands, throughout their whole extent, to be concentrated into commercially valuable pools?

In order to answer these questions satisfactorily, it will be necessary to summarize briefly all possible causes of oil and gas migration. The following table shows these classified under four main headings:

A CLASSIFICATION OF CAUSES OF OIL MIGRATION.

A. Gravitative causes.
- I. Rock pressure.
  - 1. Original.
  - 2. Secondary.
- II. Differences in specific gravities.
- III. Water pressure.
  - 1. Hydrostatic.
  - 2. Hydrodynamic.

B. Molecular causes.
- I. Surface tension.
- II. Adsorption.
- III. Adhesion.

C. Intratelluric causes.
- I. Earth movements.
- II. Heat gradient.

D. Chemical causes.
- I. Deposition of cement.
- II. Formation of gas—gas pressure.
- III. Heat due to reaction and polymerization.

Gravitative Causes (1, 3, 5, 8).

The gravitative causes depend directly upon the action of gravity for their effect. These include rock pressure, which may be defined as the pressure at any point under the surface of the earth due to the weight of the overlying rocks. Rock pressure can only be effective as a cause of motion when the rock itself is unable to sustain it and transmits this pressure directly to any liquid or gas held in its pores. Whenever burial is deep enough so that no openings can exist in the rock, the rock is said to be in its zone of flow. Rock pressure increases regularly with depth of burial. The amount of pressure and hence depth under the surface necessary to place a rock in this zone depends on its crushing strength, and consequently, varies for the different kinds of rocks. I wish to distinguish between two different kinds of rock pressures as original and secondary respectively. Original rock pressure is that due to the weight of the sediments at the time of their deposition. It results, in the main, in the compacting of the sediments into rock. Secondary rock pressure is due to the burial of the sedimentary rocks in the zone of flowage subsequent to the consolidation of the sediments.

Another gravitative cause of oil migration is to be found in the differences of the specific gravities of oil and water. Because of their immiscibility, the tendency will be for the oil to rise to the top of the water surface. The higher the porosity of any reservoir and the greater the proportion of large and connected openings, the freer the flow of liquids takes place. Oils of high-degree gravity and low viscosity are the most fluid and, consequently, are able to penetrate comparatively fine pores. Any increase of temperature is helpful because it reduces viscosity. Oils of low gravity may approximate the weight of water so closely as to afford no opportunity for a gravitative separation of this nature. In reservoirs with low porosity and in those with fine pores, the friction may be so great as to prevent all movement due to this cause.

The great majority of reservoir rocks are saturated with

water which in itself may cause oil movements (1). Thus, the water is under pressure which at any point under its surface is equivalent to the weight of the column of water above. Pressure of this sort is equal in all directions and is known as hydrostatic pressure. It is really responsible for the rise of drops of oil to the water surface. Water tends to seek its own level. The effective pressure on the water which tends to equalize its upper surface is "head." Both "head" and hydrostatic pressure are pressures possessed by water by virtue of its position or location.

Water may also flow in perceptible currents through the reservoir rocks. It will exert pressure which, in part at least, is due to its momentum. Such pressure, which results from the motion of water currents, is "hydrodynamic." Munn (3 and 4), who was apparently the first to recognize the importance of currents in localizing oil pools, applied the term "hydraulic" to these effects.

Molecular Causes (*7, 8, 9, 2, 11, 12*).

Three possible causes of oil migration owe their existence to molecular forces. The effects of two of these, adsorption and adhesion, are not clearly understood, and are probably of no great importance. Their effects are so similar that they cannot be clearly distinguished. Adsorption is a term applied to such phenomena as the condensation and retention of a gas on the surface of a solid, or the concentration of a dissolved substance on the surface of a solid or on colloidal particles suspended in the solution. All chemical reactions which are primarily the result of the interaction of films and which are apparently limited by molecular dimensions are adsorption phenomena. They are in part chemical, in part physical, and appear to be concerned only with reactions between substances or films that are molecularized. A practical illustration will make clear its effect. An emulsion of oil and water in which the individual oil drops approach molecular size would quite likely be formed during the original distillation of the parent organic matter.

Since this is in contact with different kinds of rocks and, consequently, different minerals, there may be a selective effect which results in the concentration of the oil on the surfaces of certain minerals. Thus, adsorption of this nature would require a diffusion of the oil particles through the water.

How important a part adhesion—that is the attraction of unlike molecules for each other—plays in this action is difficult to state. That certain minerals, especially metallic and basic ones, exert a stronger attraction towards oil than towards water, is proven by the success of oil flotation methods in ore dressing. The distinction, while not absolute, appears to be as follows:

Selective action of this sort that takes place in solutions is attributable to "adsorption." A similar selective action in coarse suspensions is the result of adhesion. In both cases the causive forces are purely molecular. In the first case, concentration is effected by molecular diffusion; in the second, by distinct currents.

While there may be a selective attraction of the basic rocks or minerals for oil, the writer is of the belief that the effect is negligible as an active cause of oil movement. Adsorption and adhesion may have some slight importance as conditioning factors in such migration.

The most important of the molecular causes of oil migration is the differences in the surface tension or capillary pressure of oil and water. Its effects were first clearly enunciated by Washburne (7). The rise of liquids up capillary tubes and into sponges, and the rounding of liquids into spherical drops, are familiar examples of surface tension phenomena. They are the result of the combined action of cohesion and adhesion. Thus, water rises in glass tubes with openings microscopic in size against gravity, because the attraction of the glass for the water is greater than the attraction of water for water. In other words, adhesion is the greater force. Other conditions being equal, the surface tension can be determined by observing the height to which the fluid rises in a capillary tube.

The surface tension of water at ordinary temperatures is about

three times that of crude oil. Water, therefore, exerts by far the greater pressure in entering capillary openings. The effect of this difference in pressure will be a selective action. Thus, the water will enter the openings and pores of smallest size, while the oil will occupy the openings of larger diameter. A few simple experiments furnish ideal illustrations of this phenomenon. Thus, a small block of diatomaceous earth (or chalk) suspended in an emulsion of crude oil and water of known composition, which is kept in an agitated condition to prevent gravitative separation, will absorb the water much more readily, so that after its removal and the settling of the emulsion, the proportion of oil will have greatly increased. Two glass plates wedged apart on one end so as to produce a capillary opening of sheet-like shape between them, and placed in a similar emulsion of water and oil, will illustrate the same principle. The emulsion will rise at once in the capillary sheet and separate; the water occupying the narrower portion, the oil, the wider. Both simple experiments clearly illustrate the fact that any emulsion of water and oil will tend to separate. The water, because of its superior surface tension, will occupy the openings of smaller size and will force the oil into the larger openings and pores.

Surface tension and the resulting capillary pressure are independent of direction on the whole, but in general are more effective vertically upward. This is due to two factors—the heat gradient and the increase of pressure with depth. The effect of increase in temperature is to decrease surface tension. The surface tension of water decreases at a more rapid rate than that of crude oil, so that after comparatively slight burial the surface tension of the two are virtually the same and this cause of motion becomes ineffective.

The increase of pressure with depth tends to decrease the effective openings and pores in the rocks and will eventually close them entirely. The resistance offered to a liquid that moves through capillary tubes increases with decrease in size, and, therefore, with depth of burial. Surface tension is probably most effective within three thousand feet of the earth's surface.

Intratelluric Causes.

Both earth movements and heat gradient are probably minor causes of oil movements. Folding and faulting, as well as the more persistent oscillatory movements, such as the body tides, must have stimulated migration to some extent. In general, such movements would be similar to the kneading to which a baker subjects dough, and would result in a squeezing out of the liquids towards the earth's surface. Heat gradient would have a similar effect. An increase of heat would stimulate circulation. In the case of oil, it would result not only in an expansion of volume but also in the production of gases. In general, the circulation set up would be vertically upwards. Neither earth movements nor heat gradient are as effective in causing oil migration as the gravitative causes or surface tension.

Chemical Causes (8, 10, 5)

The localization of oil pools in a reservoir rock may be occasionally accomplished by cementation (8). Thus, the gradual deposition of cement in the interstices between the grains of sandstone may force the oil to move through the rock, and may eventually collect it in an oil pool. Some oil pools occupy porous lenses in thicker sandstone beds. They appear to be pockets of oil completely surrounded by well-cemented and virtually impervious sand, and may well have been formed in this way.

It is logical to assume that the oil under the earth's surface, subjected to different temperatures and pressures, tends to polymerize and so produce new oils and gases. This tendency should increase with depth of burial, and is apparently borne out by the fact that oils show an increase in gravity with depth, and also that the proportion of gas increases with depth of reservoir. The new gases so produced may be, and in most cases are, actually above their critical temperatures and pressures. They are not true gases, therefore, but in that state of matter where the true distinction between gas and liquid disappears. These lighter hydrocarbons may be under tremendous pressure due to

their tendency to expand. Relief may be afforded by the movement of the oil. This pressure we know as gas pressure. It is checked under the earth's surface by the rock pressure and by the resistance offered to the flow of oil. High gas pressure is always favorable to production, as it promotes the rapid flow of oil. Gushers and flowing wells are characteristic of fields with high gas pressure.

In the polymerization of oil and in other chemical reactions that may take place in it, heat is liberated. This will of necessity augment the effect of the increase in temperature due to heat gradient.

All factors discussed separately probably played a part in causing oil migration. To some extent, at least, their effects can be differentiated. According to the fundamental premises of this paper, the oil is not indigenous to the reservoirs from which it is now produced. Shales are considered the real home of the oil. The causes of oil motion must be differentiated, therefore, into two classes—first, selective or segregative causes, those responsible for the movement of the oil and gas from the oil-forming shale into the reservoir rocks, and, second, concentrative causes, those which result in the concentration of the oil into commercial pools. These are shown in tabulated form:

CAUSES OF OIL MIGRATION, CLASSIFIED AS TO EFFECTS.

A. Selective or segregative causes.
- I. Essential.
  - 1. Rock pressure.
  - 2. Surface tension.
- II. Contributory.
  - 1. Earth movements.

B. Concentrative causes.
- I. Essential.
  - 1. Differences in specific gravities.
  - 2. Water pressure.
    - (*a*) Hydrostatic.
    - (*b*) Hydrodynamic.
  - 3. Cementation.
  - 4. Gas pressure.

II. Contributory.
1. Heat gradient.
2. Earth movements.
3. Heat due to reaction and polymerization.
4. Adsorption and adhesion.

The collection of the oil and gas in the reservoir rocks may be conceived of as a sort of "selective segregation" or "primary concentration" (8). It is effected chiefly by rock pressure and by surface tension aided and stimulated in a very minor way by earth movements. The original sediments which consist in greater part of muds with minor layers of sand or, perhaps, porous limestone, suffer considerable compacting at the time of their consolidation into rock. The muds especially are subject to a considerable shrinkage of volume. This decrease of volume is mainly the result of rock pressure. The sands and limestones offer greater resistance to pressure and cannot be compacted to the same degree. Their pores will hence remain open and serve as reservoirs for the liquid materials squeezed from the clays and muds. Capillary pressure also plays a rôle and probably the most important in effecting a primary concentration of oil and gas in the reservoir rocks. Thus, in the progress of time, the oil and gas produced in the shales from the organic matter buried in them will be driven out by water because of its greater capillary pressure, and will be forced into the rock with larger pores—the reservoir.

The greater the depth of burial, the more important the effect of rock pressure. The "original" rock pressure, *i. e.*, the pressure exerted at the time of compacting the sediments into rock, is probably most effective. This is active at the time of most rapid formation of oil from the recently buried organic matter. At this time the amount of water in the sediments is also greater than in any subsequent period. This, undoubtedly, aids in the rapid removal of any oil produced and its segregation in the more resistant and porous rocks.

Secondary rock pressure is that to which the sediments are subjected after they have been consolidated into rock and are

buried in the zone of flow. The same processes will of necessity still be active, and may be quite important in those cases where high pressure and perhaps heat are required to complete the distillation of residual organic matter. On the whole, however, the writer is of the belief that most oils are formed near the surface, at low temperatures, and previous to the consolidation of the sediment into rock.

Rock pressure and capillary pressure are chiefly important in collecting oil and gas in reservoir rocks. Both will be disseminated through the entire reservoir. Only under very exceptional conditions can these two forces alone cause a concentration of oil and gas in commercial quantities. Oil pools in fissured shales and limestones may owe their existence mainly to such concentration.

The concentration of oil and gas disseminated through the reservoir into commercial pools is the result of water pressure and the differences in the specific gravities of gas, oil, and water, and, to a lesser extent, of gas pressure. Cementation may be an effective localizing cause under exceptional conditions. The effects of heat, earth movements, and adhesion or adsorption are so slight as to be contributory only. In the great majority of cases the concentration of oil and gas into commercial pools is the result of the differences in the specific gravities of oil and gas and water and of the movements of the underground water. As a result, oil and gas rise to the top of the water surface, and, where currents of underground water exist, are driven ahead of the water surface through the reservoir rocks. Wherever there are suitable structural conditions, an accumulation of commercial quantities of oil and gas may take place. The term "trap" is frequently applied to such a structure.

Gas pressure and water pressure are the most important causes of flowing wells and gushers, with one or the other dominant, depending upon local conditions.

There are a number of conditioning factors upon which the movements of oil are dependent (9). These are in part due to the characteristics of the reservoir, in part due to the oil, and in

part due to local geological conditions. They are shown in tabulated form.

CONDITIONING FACTORS OF OIL MIGRATION.

A. Lithological character of the reservoir.
1. Degree of porosity.
2. Size and continuity of pore space.
3. Degree of saturation by water.
4. Proportion of induced to original openings.
5. Composition of reservoir as determining relative adhesion.
6. Effectiveness of cementation.

B. Physical and chemical character of oil.
1. Gravity.
2. Viscosity.
3. Proportion of gas.

C. Geological factors.
1. Structure.
2. Character of enclosing beds.
3. Local heat gradient.
4. Composition of ground water.
5. Depth of burial.
6. Geological history.

The characteristics of the reservoir rock are quite important in determining the relative ease of flow. Ready flow is favored by:

1. High effective porosity.
2. Large and continuous openings or pores.
3. High proportion of induced openings, such as fractures, joints, solution fissures.
4. Presence of water under pressure.
5. Cementation effective enough to hold and support the sand upon removal of oil.

The characteristics of oil also condition its movements. Ready flow is favored by:

1. High degree gravity.
2. Low viscosity.
3. High proportion of gas.

The greater the difference in the specific gravity of oil and

water, the more effective gravitative separation will be. The lower the viscosity of the oil, the less the resistance that is offered to movements through the pores of rock.

A number of geological factors influence flow. Thus, steep dips flavor flow. Unconformities of the angular type are favorable to migration because of the more rapid concentration of oil from the lower series into the unconformable one above, due to the greater ease of travel along beds than across them. Certain sands are so friable that large quantities of sand are ejected from the wells. Oil flow is favored in these by the presence of strong resistant enclosing beds above and below the reservoir. Locally high heat gradient has the double effect of lowering the surface tension and decreasing the viscosity of oil. On the whole the effect will be to stimulate circulation. The presence of sulphated ground waters is obnoxious because it results in the production of sulphur compounds in the oil and increases its specific gravity and viscosity. The latter two render the oil less mobile. Depth of burial determines temperature and pressure on the oil, the effect of both of which has already been discussed. The past geological history of an oil field often gives us an explanation of peculiar localization of oil pools. Frequent oscillations in elevation of a district result in changes in the water level and must of necessity stimulate oil movements.

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THE COPPER SILVER VEINS OF THE TELKWA DISTRICT, BRITISH COLUMBIA.

V. DOLMAGE.

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INTRODUCTION.

The following is a brief summary of some of the results which were obtained by the writer in an investigation of the geology and mineral deposits of the Telkwa district. The field work was done during the season of 1915 under the direction of the Geological Survey of Canada. This work was supplemented by a considerable amount of petrography and mineralography carried on in the laboratories of the Massachusetts Institute of Technology and under the very helpful and inspiring supervision of the geological staff.

LOCATION.

The region in which these veins occur comprises approximately 40 miles from east to west and 22 miles from north to south, and

is situated so that the northeast corner lies a few miles south of the town of Telkwa, on the Grand Trunk Pacific railway, at a point about 300 miles east of Prince Rupert. The only means of communication between the interior parts of the district and the railroad are two wagon roads and a number of trails.

TOPOGRAPHY.

The country is mountainous, lying about on the boundary of the two physiographic provinces known as the Coast Range system and the interior plateau. It is bounded on the west by a rugged spur of the Coast Range and on the east by the broad valley of the Bulkley River. In the centers of the east and west halves of the area are two similar and roughly circular groups of mountains, separated from each other and from the Coast Range by deep glacial valleys of the type known as "through valleys." These valleys cut sharply into the gentle slopes of an old mature erosion surface and have the peculiarity of extending through to adjoining drainage systems with very low divides, usually flat and marshy. Each of the two mountainous areas reaches an elevation of about 8,000 feet, and the Coast Range rises to about 9,000 feet. The Bulkley valley in this district is below 2,000 feet. Each of the mountain masses has radial drainage and the streams occupy deeply cut glacial valleys which head in cirques, many of which are still occupied by active glaciers. The cirques extend well back to the center of mountains in many places being separated only by sharp arêtes, indicating that the glacial cycle of erosion has developed to a mature stage.

GEOLOGY.

The geology of the area is directly related to the topography since each of the three mountainous areas has at its core an intrusion of plutonic rock, which cuts through the old tuffs of the Hazelton formation.

The oldest rocks of the district make up the Hazelton formation, which is thought to be Triassic or in part Jurassic in age. The formation has an areal distribution of many thousands of square miles in northern British Columbia, and a total thickness

estimated by Dawson to be not less than 1,000 feet. With the exception of a small thickness of sandstone and shale containing a minor amount of coal, the entire formation is composed of volcanic rocks, and of this, 95 per cent. of the thickness, exposed in the Telkwa district, consists of tuffs. These tuffs are characteristically red in color, and vary in texture from coarse breccias with fragments up to a foot in diameter to an extremely fine cherty rock whose nature could not be determined without the aid of strong magnification. The prevailing texture, and the one which was responsible for the formation being called by Dawson the "porphyrite group," consists of a fine, reddish, hard groundmass plentifully sprinkled through with conspicuous white feldspar crystal fragments averaging about 3 millimeters in length.

The chemical composition of the rock is about that of an andesite. It consists mainly of small glass fragments in various stages of devitrification and containing many minute particles of hematite. These are cemented with a siliceous matrix also containing a high proportion of hematite powder which gives the rocks their characteristic color. No ferromagnesian silicates are present excepting a considerable amount of secondary chlorite. At the contacts of the recent intrusions the tuffs are metamorphosed for distances from the contact up to a mile. The chief alteration has been the development of a large amount of very pale green biotite, a considerable amount of sericite and silica, and the change of hematite to magnetite thus changing the color from red to black. These rocks underlie nearly the whole of the district excepting the small areas occupied by the later intrusions.

The oldest intrusive rocks are those of the Coast Range batholith thought to be of Jurassic age. They form the main body of the Coast Range in this district and also the small stock-like intrusion composing the core of the eastern of the two mountainous areas mentioned above, known as the Telkwa Mountains. The rocks of these two localities are practically identical in composition and appearance. They are quartz diorites and granodiorites having a medium coarse texture and a light gray color.

Younger than these, and cutting sediments of known Cretaceous age outside the district here considered, are many small intrusions forming sills and dikes, which Leach has grouped together into what he calls the Bulkley intrusives. These intrusions are of two different rock types, acid members of a peculiar composition, being high in soda, low in potash and medium high in silica; and basic members lamprophyric in composition. In hand specimen the acid type has a reddish pink color, and is seen to be composed of a close aggregate of pink tabular feldspar phenocrysts, uniform in size, having an average length of 4 millimeters evenly distributed in a scant light gray groundmass, sprinkled with small grains of iron oxide. Under the microscope the phenocrysts were found to be albite, and their pink color is due to abundant decomposition products, mainly hematite. The groundmass consists of quartz, sericite, orthoclase, chlorite and hematite. The quartz is the most abundant, while the orthoclase is almost negligible in amount. The hematite forms pseudomorphs probably after amphibole.

This rock occurs only in the western half of the area where it forms the core of the western mountain group called the Star Mountains. It forms an exceedingly irregular mass with numerous long tongues or lobes projecting out in three dimensions. It would be difficult to classify it with any of the common types of injected bodies but it seems to fill all the conditions of Professor Daly's definition of a chonolith.

The basic members of the Bulkley eruptives occur in all parts of the area, usually but not always forming dikes, and have played an important part in the mineralization of the district. They contain such rocks as diabases, kersantites and odenites, diabases being the most common.

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A considerable amount of mineralization has been produced along the contacts of all the above-described intrusions, and while no large ore bodies have as yet been discovered in the district, there are many small deposits, some of which are rich in copper, gold and silver. According to their geographical dis-

tribution, their geological associations and mineral composition, the deposits fall naturally into three groups, namely: those which lie close to the contact of the main Coast Range batholith; those near the contact of the intrusion which forms the core of the Telkwa Mountains; and those scattered over the district but always associated with one of the later Bulkley eruptives. Each of these groups has its own peculiar association of minerals and structure, but in several instances the same veins have come under the influence of mineralizing solutions of both the batholithic rocks and the Bulkley eruptives giving an ore of a very striking and unusual type.

THE VEINS LOCATED AT THE CONTACT OF THE COAST RANGE BATHOLITH.

These veins are of considerably less economic importance than the others and are represented by two small groups of claims situated south of Clear Creek in the northwest corner of the area. The veins are irregular in width and direction; in some places forming a tangled network of veinlets an inch or less in width and in others forming large lenticular bodies 15 feet wide. The longest of these veins was traced for 1,500 feet.

The gangue consists almost entirely of milky quartz with small inclusions of highly silicified country rock. A slight tendency to banding can be detected. Small vugs, a few centimeters in size, occur plentifully in the quartz, and contain small crystals of quartz and of brilliant pyrite.

The ore of these veins consists of large masses of galena with small segregations of chalcopyrite, often containing crystals of quartz 5 to 6 centimeters in length. Under the metallographic microscope, besides the galena and chalcopyrite, zinc blende, minute quantities of argentite, tetrahedrite, covellite, and hematite were seen. The galena forms about 90 per cent. of the ore, and the chalcopyrite the larger part of the remainder. The chalcopyrite occurs as small, irregularly shaped grains in the galena with smooth, rounded contacts, which suggest simultaneous deposition. The argentite is also found in the galena but in very

small blebs, often situated at the points of the irregular grains of chalcopyrite. The tetrahedrite occurs in only microscopic amounts, and is seen as small rounded areas in the galena with smooth contacts which indicate a probable simultaneous deposition.

All the minerals are cut by small veinlets of limonite, along some of which were seen a little covellite. The smooth contacts of some of these veins undoubtedly indicate replacement, but others have sharp, angular contacts which show that they occupy cracks formed by crushing of the ore. Malachite and azurite are present in small amounts.

The alteration of the country rock is intense. The tuffs are changed to a light green, fine-grained rock somewhat like propylite, containing visible grains of quartz and pyrite. Under the microscope it is seen to consist almost entirely of about equal amounts of chlorite and sericite with a little epidote in a fine-grained mass of quartz. In this groundmass are enclosed corroded crystals of quartz which are probably primary, and have been partly replaced by sericite and chlorite. Later than all these minerals are numerous small veins of quartz. The granodiorite is altered to sericite, quartz and chlorite, and slightly impregnated with pyrite.

The order in which the minerals were deposited, as indicated by the veining of the earlier by the later minerals, is as follows:

I. { Epidote,
Sericite,
Chlorite,
Quartz.

II. { Quartz (gangue).

III. { Pyrite,
Zinc blende,
Chalcopyrite,
Galena,
Tetrahedrite,
Argentite.

IV. { Limonite, Covellite, Azurite, Malachite.

The proximity of these veins to the batholith, their association with the altered volcanics which persist along the contact, and their extension into the granodiorite itself are considered as strong evidence that the veins are derived from solutions which emanated from the intrusion. The presence of gold and silver with lead, copper, antimony and zinc; the association of pyrite, galena, chalcopyrite, tetrahedrite and zinc blende; the absence of any large amounts of arsenic, molybdenum and such oxides as magnetite, hematite and ilmenite or such silicates as biotite, pyroxene, amphibole and tourmaline, and the general simplicity of the deposit are all evidence that these veins were formed by heated solutions at intermediate depths.

THE VEINS SITUATED IN THE VICINITY OF THE GRANODIORITE INTRUSION AT THE CORE OF THE TELKWA MOUNTAINS.

The deposits of this group contain much more copper and silver than those of the first, and include the most promising claims of the district. Besides their greater economic value, they also possess a greater scientific interest because of the complexity and singularity of their mineral associations and types of structure.

The group consists of ten or more slightly developed claims. From three of the number, enough ore has been extracted from small tunnels and open pits to make smelter shipments.

The situation of these deposits bears a direct relation to the contact of the granodiorite intrusion, in that they form a ring around the stock, none of them being farther than 1½ miles and none nearer than a mile. They are also situated just outside of a zone of intense metamorphism which surrounds the stock. Almost all the claims are at an elevation of about 6,000 feet and all happen to be exposed just where the steep walls of the glacial valleys intersect the gentle slopes of the old upland.

The deposits are characterized by an abundance of bornite,

chalcopyrite, chalcocite, hematite and tetrahedrite, associated with epidote and quartz.

There are two types of deposits, those consisting of small replacement bodies disseminated through a porous and highly epidotized bed of tuff, usually more highly concentrated along joint fissures which cut the bed vertically; and those which are clearly open fissure fillings, with well-defined walls, and a gangue of banded quartz.

The Replacement Type.

The best example of the replacement ore bodies is the Excelsior claim in Dominion basin, one of the most promising deposits in the district. The mineralized bed of tuff outcrops on the nearly vertical wall of the basin at an elevation of 5,750 and 300 feet above the bottom of the basin. This bed, which is highly altered and carries a large amount of bornite, chalcopyrite and chalcocite, is interbedded with the typical unaltered tuffs of the Hazelton formation. The strata dip about 18 degrees to the south, away from the contact. Near the south end of the outcrop the tuffs are cut at nearly right angles by a 20-foot diabase dyke which carries a small amount of chalcopyrite and a large amount of magnetite.

The tuffs adjoining the mineralized bed are purplish, dense, fine-grained rocks with conspicuous crystal fragments of feldspar up to a centimeter in length, and are typical of most of the tuffs of the Hazelton formation. Close to the ore-bearing bed they are highly impregnated with epidote, and near the ore shoots contain a considerable amount of bornite and chalcopyrite.

The Mineralized Bed.—The bed which carries the copper is an unusual rock both in appearance and composition, due to its nearly complete alteration to hornblende and epidote. The most normal phase, or that which is encountered at a distance from the ore shoots, is a yellowish-green rock, containing in a dense, fine-grained groundmass, phenocrysts of green, fibrous hornblende up to 3 or 4 millimeters in diameter. Under the microscope it was found to consists entirely of epidote and hornblende in about equal amounts, with a very few grains of hematite, and a great

number of small pores. The groundmass consists of small, rounded grains of epidote in a mesh of fine actinolite needles. The amphibole is a dull grayish-green color in hand specimens and in thin section is a pale, slightly bluish-green with an indistinct pleochroism. It has a marked fibrous structure with positive elongation, negative double refraction, and an extinction on the fibers of 10 to 20 degrees.

Adjoining the ore shoots, the rocks contain, in addition, garnet, a little quartz, more hematite and magnetite, and a dark-greenish calcite apparently colored by a fine network of actinolite fibers.

Under the microscope no other minerals were seen. The epidote, which forms about 50 per cent. of the rock, or more, occurs as phenocrysts about 2 or 3 millimeters in length, and also as a close aggregate of small round grains a fraction of a millimeter in diameter. The fibrous hornblende is not so plentiful as in the rock farther from the shoots, and does not occur as phenocrysts but forms a large portion of the groundmass. Grains of quartz were observed in the sections filled with fine, hair-like crystals of actinolite. The garnets are the next most plentiful mineral after hornblende. They form grains several millimeters in diameter showing a slightly yellowish color, and always a strong anomalous double refraction. Magnetite, like calcite, is a late mineral and is found in veins cutting through the rock and as crystals in open vugs.

The Ore.—The ore occurs in shoots, extending across the beds almost at right angles, and often penetrating the adjoining beds. They have flat, elliptic outlines, with the major axis vertical, when sectioned perpendicular to the bedding, and have an average width of about 6 feet. Their size is, however, somewhat variable and they are not regularly spaced. They are shown in Fig. 48.

The centers of the shoots are composed of a band of almost solid bornite irregularly replacing the epidote more or less completely for a width of several inches. The limits of these bands are not clearly defined, the bornite simply becomes more sparsely

disseminated with increasing distance from the centers until no ore minerals can be seen without the aid of a microscope. In the leaner parts of the ore shoots, chalcopyrite becomes evident and with the bornite shows a tendency to occupy small rounded cavities about the size of the phenocrysts of the unmineralized portions of the bed. The boundaries between the sulphides and epi-

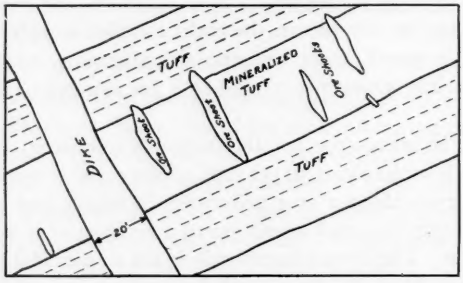

FIG. 48. Section of ore bed of Excelsior Claim.

dote are in all cases extremely ragged. No sharply bounded veins are found in the ore.

The study of the polished sections reveals chalcopyrite, bornite, chalcocite, zinc blende, galena, covellite, hematite, magnetite, limonite and ilmenite.

Bornite constitutes about 75 per cent. of the sulphides present. It forms in places solid streaks up to 2 inches in width extending along the shoots for many feet, and is also plentifully distributed in the disseminated ore.

Considerable chalcocite is intimately associated with the bornite. It is of a dull grayish-blue variety, often showing streaks of a lighter color, arranged in a reticulate pattern. It forms mutual contacts with the bornite, and the graphic intergrowth is exceedingly common. Many places were found in the polished sections where the bornite after forming a narrow, regular rim between the chalcocite and the gangue would branch into the chalcocite forming a true graphic structure. The reverse of this was also found where the chalcocite formed rims and branched

FIG. *A*.

MAGNIFIED 64 DIAMETERS.

Chalcocite rimmed with bornite, which also develops into the "graphic structure." *CC*, chalcocite; *B*, bornite; *G*, gangue.

FIG. *B*.

MAGNIFIED 63 DIAMETERS.

Bornite replaced by veinlets of chalcopyrite and chalcocite. *B*, bornite; *Cp*, chalcopyrite.

FIG. *C*.

MAGNIFIED 2,000 DIAMETERS.

Bornite and chalcocite replaced by hematite and chalcopyrite. *H*, hematite; *G*, quartz.

FIG. *A*.

MAGNIFIED 390 DIAMETERS.

Bornite and chalcocite replaced by chalcopyrite and chalcocite. The late chalcocite lines the chalcopyrite vein labeled *Cp*. *B*, bornite; *Cp*, chalcopyrite; *G*, galena; *Q*, quartz.

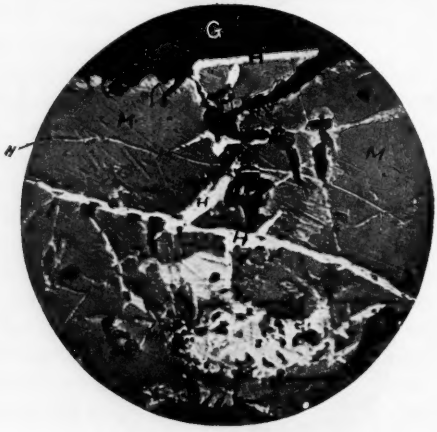

FIG. *B*.

MAGNIFIED 425 DIAMETERS.

Magnetite replaced by hematite. *M*, magnetite; *H*, hematite; *G*, gangue.

into the bornite. The former relation is shown in Plate XXIII., *A*. The contact between the two minerals in many places is not sharp but the one color fades out very gradually into the other, forming a mixed zone. Besides this chalcocite there is some of a distinctly secondary nature which follows minute fractures cutting through the bornite-chalcocite intergrowths. Where the fracture traverses bornite areas it is lined with this secondary chalcocite, and where it crosses the chalcocite, covellite is deposited. These veinlets frequently have chalcocite centers and chalcopyrite margins, as shown in Plate XXIII., *B*.

Chalcopyrite occurs sparingly in all the specimens and like the chalcocite is of two generations. It occurs as a primary mineral in the gangue sometimes occupying spaces which were originally phenocrysts, and also in the bornite where the smooth rounded contacts, and mutual intergrowths indicate a contemporaneous deposition with that mineral.

It also commonly occurs in a distinctly later generation, and frequently forms extremely narrow but persistent borders between the bornite and the gangue, or between the bornite and the hematite, in places penetrating the bornite along minute fissures. These fissures often contain chalcocite in their centers and cut independently both chalcocite and bornite. The replacement has not gone far but numerous small spikes of chalcopyrite can be seen shooting out into the bornite along crystallographic lines as if an early stage of the lattice structure were being developed. This is shown in Plate XXIII., *B*; the white mineral is the chalcopyrite. Plate XXIV., *A*, shows one of these veinlets cutting across a bornite area into an area of chalcocite.

Galena is sparingly present and is found only in the bornite and bornite-chalcocite graphic structures, where it forms small blebs or more often fine films appearing as almost submicroscopic lines in the polished sections. These films are usually arranged in one definite direction, and are probably controlled by the cleavage of the bornite. Their arrangement is, however, only approximately maintained and the thickness is also quite variable. They have no connection with any fractures and are undoubt-

edly of primary origin. A small bleb of galena is shown in Plate XXIV., *A*.

Zinc blende was found in only one specimen where it appeared as medium-sized grains, which contain numerous small specks of chalcopyrite, and in one case bornite.

Magnetite and hematite are, as usual, abundant. In some portions of the mineralized bed magnetite forms large veins, associated with quartz and epidote, or occurs in well-developed octahedrons on the walls of open cavities. Hematite is pentifully associated with the magnetite and has extensively replaced it along fine ramifying veinlets and also along regular crystallographic lines, in the latter case forming a reticulate structure. Veinlets often follow the line between the magnetite and the gangue. The replacement of the magnetite is shown in Plate XXIV., *B*. Hematite is more plentiful in the ore than in the wall rock and greatly exceeds the amount of magnetite. It is replaced by hematite and sulphides; grains of it are frequently seen coated with a shell of bornite, or chalcocite, or both. The hematite on the other hand replaces the sulphides and very faithfully follows the contacts between the sulphides and gangue.

Calcite is later than the hematite and other minerals, and occupies small veins irregularly cutting the ore. It is, also, found in veinlets following the contact of the hematite and epidote. A vein of this calcite is shown in Plate XXIII., *A*, as a black line between the gangue and the sulphides.

Paragenesis.—As well as can be made out from the structures seen in polished sections the order of deposition of the minerals is as follows:

I. { Epidote,
Hornblende and actinolite,
Quartz,
Hematite.

II. { Zinc blende,
Chalcopyrite,
Bornite,
Chalcocite,
Galena.

III. { Magnetite,
Hematite,
Chalcopyrite.

IV. { Chalcocite,
Covellite,
Calcite.

The sequence in each separate group is not to be inferred from this arrangement for in each of the four periods some or all of the minerals were deposited simultaneously, or the order alternated from one sequence to the other. This is particularly true of the second group in which the order of the bornite and chalcocite is reversed from bornite-chalcocite to chalcocite-bornite, and it is clear in other places that both minerals were being deposited simultaneously. The relations of the chalcopyrite and bornite in this group indicate a contemporaneous deposition for some, and a later deposition for other portions of it.

Genesis.—The processes which brought about this complicated and apparently unusual sequence of mineralization are believed to have taken place as follows:

After the intrusion of the granodiorite stock, the adjoining tuffs suffered an intense thermal and hydrothermal alteration, producing a metamorphic zone extending half a mile or more away from the contact in all directions. This metamorphism was characterized by silicification, biotitization, with the dissemination of epidote, copper and iron sulphides, and a little silver. In certain porous beds a large amount of hornblende was produced, with epidote, magnetite and hematite. In these beds the mineralizing solutions and vapors were able to travel faster and thus produce a more intense alteration and to develop it farther from the contact than in the less porous beds. The first and hottest heat waves to pass off from the intrusion produced the metamorphic zone, and seemed to have the effect of closing any fissures which may have existed, for there were no veins of any kind seen in this zone. Beyond this, many fissures remained open, forming channels along which the solutions flowed and deposited the minerals which now form the richer veins of the district.

The minerals produced in this period were epidote, hornblende, actinolite, quartz and a small amount of magnetite and hematite.

Following this, came a period of mineralization at a much lower temperature, which deposited the zinc blende, chalcopyrite, bornite, galena and chalcocite and produced much chlorite in the tuffs.

Then came a period of igneous activity in which the late dikes were intruded, followed by a second period of high temperature mineralization which produced the hematite, magnetite and chalcopyrite, which characterize this period of mineralization throughout the district.

Much later than this, a slight amount of surface oxidation and enrichment has taken place, developing the covellite, chalcocite and calcite.

The Open Fissure Type.

This type of deposit is represented by five principal deposits: the High Grade, the King and Rainbow, and the Hunter, Idaho and Colorado.

The first two are the most valuable, and because they were affected by both periods of mineralization are much more complex than the others. They will be described separately. The other three, which are less important and more simple, will not be described in this paper.

The High Grade.—This claim contains the highest grade ore to be found in the district, and though rich in copper and silver, unfortunately is not plentiful, and being remotely situated, is not, under present conditions, worth the cost of its transportation.

The claim is located at the top of the high, steep wall of a large glacial valley occupied by Sunset creek, and is slightly more than one and one half miles southwest of the contact of the granodiorite stock. The cliff is almost perpendicular and well exposes the thin-bedded, bright red tuffs for a vertical distance of 150 feet below the upland plain which intersects the valley wall at an elevation of 6,000 feet.

Cutting the tuffs and striking in a southerly direction are two dikes of diabase, one about 15 feet in width is situated 100 yards

to the east, and a smaller one outcrops 30 feet below the tunnel and on the east side.

Structure.—The tuffs here are folded into a low anticline with dips of about 20 degrees, and a plunge to the south of about 8 degrees. Almost on the axial plain of the fold the beds are ruptured along an irregular fissure, and it is in this that the mineral has been deposited.

This vein is exposed at intervals from the top of the cliff down to the edge of a glacier below, but owing to the thin deposit of soil cannot be traced along the surface of the plain. About 20 feet above the glacier the tunnel penetrates the cliff for about 20 feet along the vein. A few tons of ore were extracted from the tunnel, and samples taken from the ore dump assayed: gold, 0.03 oz.; silver, 27.6 oz.; copper, 18.8 per cent. The vein varies from 1 inch to 12 inches in width with a general vertical dip. In places on the outcrop it breaks up into a number of lenses separated from one another and only roughly following a linear arrangement. What appears to be on offshot of the main vein can be traced for 30 feet up the cliff above the tunnel to the west of the main vein, and has a dip to the east of about 70 degrees. The walls of the vein are sharply defined and little changed.

The Ore.—The ore consists of almost pure chalcocite in a gangue of quartz; the only other minerals which can be seen in the hand specimen are a little native silver, hematite associated with epidote, calcite, and a very small amount of malachite, azurite and laumontite. The chalcocite appears to be equal to or even to exceed the amount of quartz, and gives the ore a white silvery appearance which to the eye suggests much higher values than the assays give.

In general the ore is massive, and has an even medium-grained texture, but in places comb structure becomes evident. In other places the quartz forms small rosettes of radiating euhedral crystals. The epidote is confined to a narrow band along the east wall about an inch in width and to much smaller veinlets penetrating the more central parts of the vein. The hematite is closely associated with the epidote.

The microscopic study of the ore showed that bornite, argentite, chalcopyrite, covellite and hornsilver are present, besides the minerals already named.

The chalcocite is of two kinds, a pure white variety, which forms the bulk of the ore, and a bluish form, which is present in only small amounts. The white chalcocite is quite homogeneous, and when etched is seen to be formed of rounded but distinct crystals closely fitted together in small spaces in the quartz. It clearly replaces the quartz, in some places forming small veinlets and rounded shapeless masses, but it undoubtedly also fills many spaces, which were once empty cavities, the crystal outlines of the quartz being still preserved. Some of the larger areas which have diameters up to three fourths of an inch occupy cvaities of this nature. Almost all of the larger areas have peculiar cracks crossing them, which fade out towards the margins and become wider at the center. None of them were seen to cross from one area of chalcocite to another and all were of this peculiar shape. The size of the cracks varies directly with the size of the grains in which they occur, those in the largest grains can easily be seen with a hand lens. They strongly suggest shrinkage cracks and are of constant occurrence. Some of them are filled with calcite or other gangue minerals, while many of them are empty.

The blue chalcocite is confined to the epidote areas and is frequently traversed by wide open cracks along which it is altered to covellite. In the epidote band on the vein wall there is much blue chalcocite in the form of rounded irregular grains not connected with any veins, and which are all cracked and altered to covellite. They seem to be residual grains which have been altered by the solutions which deposited the epidote. Simliar chalcocite was found in the calcite, but some of it appeared to replace it along small veinlets.

Bornite was observed in only one specimen, and here in microscopic amounts, but is said to have been rather plentiful since the time of the examination, in the small branch vein to the east and some 30 feet above the tunnel. The bornite, which was found in one of the specimens at hand, did not show its relation

to the chalcocite and their relative ages cannot, at present, be learned. The unusual structure of this bornite is shown in Plate XXIII., *C*. A band of bornite of uniform width in a chalcocite field follows a vein of hematite faithfully but is separated from it by a narrower margin of chalcocite. It also shows a similar band of bornite following the gangue contact, and separated from it by a similar band of chalcocite. Small spikes of chalcopyrite project into the bornite; they appear as white in the figure. A probable explanation of the structure is that the bornite bands are residual remnants after the replacement of the rest of the bornite by chalcocite, these being protected from the replacing solution by the solution pressure of the iron of the nearby hematite.

Chalcopyrite does not occur in the ore excepting in the minute spikes just mentioned, and as a few stray grains in the quartz.

Native silver can be seen in all of the specimens of the ore in which calcite is present. The chalcocite is nearly always blue when near the native silver. It was never observed in contact with the white chalcocite and its age can only be determined indirectly. In one specimen it was replaced by hornsilver.

Argentite is only found surrounding the silver and is not plentiful. It is later than the native silver, and was also seen filling cracks in the chalcocite.

Malachite and azurite occur incidentally as secondary minerals.

Hematite, the characteristic and ever-present mineral in this district, is present in large amounts and is most plentiful where epidote and calcite occur, especially in the epidote band throughout which it is disseminated only in the form of small blades. Wherever the epidote has penetrated the ore, the hematite is closely associated with it, but it has itself penetrated much farther. Microscopically small veins of it are seen in every specimen. These veins (see in Plate XXIII., *C*) have a strong tendency to follow the chalcocite-gangue contacts. These lines probably offered the least resistance, and were, therefore, usually selected by the iron-bearing solutions, but one also finds the veinlets running across the chalcocite sometimes cutting off small peninsulas of the chalcocite which jut out into the quartz. Another habit of the hema-

tite, and a difficult one to explain, is that of following the gangue contacts very regularly, but inside the chalcocite areas, and separated from the contact by a narrow border. Aggregates of it do not occur excepting near the epidote and calcite. It would appear from this that the hematite came in at the same time as the epidote, and some time after the formation of the quartz-sulphide vein.

No magnetite was seen in the ore excepting a few scattered grains near the margins of the veins.

Of the gangue minerals, quartz is the most important. It is unusually full of inclusions of transparent and opaque minerals. Some of them are undoubtedly hematite blades, but these are not sufficiently plentiful to color the quartz, and must, therefore, form a very minor portion of the inclusions. Many of the inclusions are filled with liquid, and contain movable bubbles. The inclusions are arranged in lines which are roughly parallel, but are not straight, and conform to no apparent system.

Epidote is next in importance among the gangue minerals. It forms a band an inch, or more in thickness, on the east wall of the vein which is yellowish-green color, and has a sugary texture. From this band numerous veinlets branch off irregularly into the ore. It is occasionally seen in euhedral crystals in the calcite, and is of an earlier period than the calcite.

Calcite occurs as irregular masses in the ore several inches, or more, in size, and also as veinlets cutting the quartz. It contains only blue chalcocite, the silver minerals, and copper carbonates, all of which replace it along cleavage lines.

Laumontite was found rather plentifully along the margins of the vein; it has a light pink color, and soon crumbled away when exposed to the air. It was seen in one of the thin sections and determined by its optical properties.

Alteration of the Country Rock.—The tuffs adjoining the vein are surprisingly little altered. The color is changed from a red to a slaty green, and chlorite, epidote, quartz and occasionally a little laumontite along the walls have been introduced. The alteration does not extend more than a few inches from the vein. Adjoining the dikes the alteration is more intense, and consid-

erable silicification, and some epidotization with the introduction of considerable hematite, has taken place. No sulphides were seen in the dikes or near them.

Paragenesis.—The observed structural relations could all be satisfied if the minerals had been deposited in this order:

Quartz,
Bornite,
Chalcocite.

Epidote,
Hematite,
Calcite.

Silver,
Argentite,
Hornsilver,
Chalcocite,
Chalcopyrite,
Covellite,
Malachite,
Azurite.

There is no doubt that the quartz was the first mineral to be deposited in this vein, and the copper sulphides are so closely related that they must have followed very soon after, if indeed they were not deposited at the same time. Such a close and intricate intergrowth of quartz and sulphides is not often seen. The relative ages of the copper sulphides is not so certain, and there are two possible explanations: one that bornite, and perhaps chalcopyrite, were deposited by primary solutions, and were afterwards replaced by the chalcocite; the other, that the three sulphides were deposited as primary minerals at about the same time. The first view, though quite possible, is supported by no visible facts except that there is bornite present. It is, however, supported by theory founded on numerous observations made in other parts of the world, and is the explanation which would, for

this reason, be accepted by those who believe that chalcocite is never a primary mineral. The primary theory, on the other hand, is in strict accord with the facts, and conflicts with nothing but theory. The subject will be more thoroughly discussed in a later paragraph.

The epidote, hematite and calcite are of a distinctly different age and due to solutions of a different nature and temperature. This is not only proven by their occurring in veins which cut the other minerals, but is also strongly suggested by the close association of these minerals, particularly hematite and epidote, and their entirely different habits from the sulphides. The invariable rule of the epidote being associated with blue chalcocite of a probable residual nature is also evidence that the epidote was deposited after the chalcocite. The calcite is later than the hematite and epidote.

The other minerals are found in the calcite usually replacing it along cleavage lines.

Genesis.—The point to be noted in discussing the origin of this deposit is the replacement of the chalcocite along small veinlets, by hematite with the association of epidote and calcite.

The succession of relatively low-temperature minerals followed by such high-temperature minerals as hematite, can only be explained by the theory of two periods of mineralization, as at the Excelsior claim. Moreover the composition of the later mineralizing solutions containing hematite, epidote and calcite is also very suggestive of the type always found associated with the later basic dikes, one of which is located within 30 feet of the adit from which the ore was taken.

The composition of the primary ore is not exactly the same as that of the other claims, which are believed to have derived their minerals from the same source, *i. e.*, the granitic stock, but the presence of so much native silver associated with the secondary minerals, indicates that some silver mineral must have been in the primary ore. In view of this, the only difference between this ore and that of the other deposits is a lower per cent. of iron, producing chalcocite instead of bornite, a difference not sufficiently

important to shake the theory that the primary ore of this claim also came from solutions emanating from the granitic stock.

According to this theory, it matters not whether the chalcocite be considered as primary, or as secondary after bornite, and that the hematite followed the bornite-gangue contacts instead of the chalcocite-gangue contacts, but for reasons that will be given in a later paragraph the chalcocite is believed to be primary.

Primary Chalcocite.—One of the most disputed points in the current literature on economic geology, and at the same time a most critical point, is the question whether or not chalcocite is ever a primary mineral. It is conceded by all that it is a most common secondary product, and while a few believe that it may, in rare cases, be primary yet there are many who maintain that no case of the primary origin has yet been proven. It is, therefore, with some timidity that I claim for this chalcocite a primary origin, though the evidence seems to point strongly in that direction. The importance of the matter rests on the question, whether the mineral can be taken as a positive criterion for proving the ore in which it is found to have been enriched by descending meteoric waters.

Some of the strongest evidence against the enrichment theory for this ore comes from the relations observed in the Excelsior claim. The microscopic structures show fairly certainly that some of the bornite of the graphic structures is of later date than some of the chalcocite. Areas of chalcocite surrounded by narrow persistent rims of bornite which send sharp wedge-shaped spikes into the chalcocite cannot be explained in any other way, and such were seen in several cases. The bornite rims are often connected with the bornite of the graphic structure, as for example, in Plate XXIII., *A*. This being the case, then, if the chalcocite is secondary, the bornite must also be considered secondary. But there is no evidence to substantiate this, the bornite is often closely associated with the chalcopyrite, but there is no sign of veining or replacement along the gangue contacts, or indeed any structural evidence of secondary replacement. On the contrary their smooth, rounded contacts, and mutual intergrowths indicate a contemporaneous and a primary origin for both. The

relation of the galena to the bornite is also indicative of the bornite being primary. The small scattered and rounded grains of galena in the bornite resemble very strongly the type of structure seen in zinc blende, which is not known to ever have had a secondary origin. The occurrence of bornite specks in zinc blende, and also in magnetite, is still further evidence in favor of its primary origin.

Aside from the chalcocite, there is no mineralogical evidence that secondary processes have played a part in the formation of this ore. Pyrite is entirely absent from the ore-bearing bed itself, and from any of the nearby country rocks, since it is confined to the metamorphic zone. And without this mineral or marcasite to supply the iron sulphates for lixiviation, it would be difficult to obtain enrichment in this type of deposit. Such minerals as chalcedony and opal, which are strongly indicative of enrichment processes, are not present.

In the case of this deposit, too, the geological conditions are very strongly opposed to the enrichment theory. Here is a bed only 20 feet thick, with a dip of only 18 degrees, buried under 1,250 feet of barren tuffs whose original thickness must have been much greater. It is exposed to the surface only on a vertical wall of a glacial cirque formed long since glacial time, and contains ore shoots of, in places, almost solid bornite and chalcocite. In the absence of a leached zone above, but instead, an overburden of 1,250 feet of barren tuffs, where could the enriching metal come from? Supposing this were a chalcopyrite deposit so enriched, and then consider the amount of copper which would have to be brought from the overlying rocks. Chalcopyrite contains 34.5 per cent. copper, and a unit volume of bornite and chalcocite in equal amounts, contains about 67 per cent. copper, therefore, since replacement takes place volume for volume, the replacement of chalcopyrite by a mixture of this kind, which is very similar to the present case, would involve almost doubling the original amount of copper.

There is also much good evidence for believing the chalcocite of the High Grade claim to be of primary origin.

The entire absence of any of the replaced minerals, excepting the almost inconsiderable amount of bornite, is in itself opposed to the theory of enrichment in this case.

The chalcocite for the most part is enclosed in small cavities in the quartz in a manner that would make it difficult for the replacing solutions to act freely enough for even a partial replacement.

There is an absence of any indication of enriching processes in many of the claims of the district, such as the King and the Hunter, both of which contain an abundance of bornite, the most sensitive of all minerals. This could hardly be expected if in the High Grade all the primary minerals were swept clean by enrichment solution.

The cracks, which occur in the chalcocite, as described in a previous paragraph, are of such a nature that they cannot be explained in any other way than to consider them as due to shrinking. According to the accepted notion of replacement of bornite by chalcocite, there is no change in volume, the chalcocite simply passively occupies the space left by the dissolving of the bornite. Nor have such structures been observed by the writer in the study of secondary chalcocite, and neither have they been described by other authors. It has been proven that there is an inversion point at about 91 degrees at which the orthorhombic form of chalcocite goes over to the isometric. This temperature is in all probability below the temperature at which primary chalcocite would be formed and we must, therefore, expect an inversion from one form to the other at the time the sulphide passed through that temperature. The volume change involved in this inversion has not been determined but from what is known of the other polymorphous substances one would expect the low temperature form to have the lesser volume. The inversion of small, rounded masses of chalcocite enclosed in quartz would inevitably produce such shrinkage cracks. If this assumption is correct, it ought to be a good criterion for primary chalcocite, not only in this instance, but in general, where the chalcocite is so related to the gangue that the decrease in volume would cause cracking.

It might be argued that the absence of chalcopyrite from this

ore, when it is such a persistent mineral in all the other veins of the district, is evidence of enrichment having taken place, but its absence would naturally be expected since the primary solutions would of necessity be low in iron in order that chalcocite could be deposited with only a trace of bornite.

The native silver might be regarded as evidence of enrichment, but it is later than the calcite, which for the most part is later than the white chalcocite, though earlier than the blue chalcocite. It is, therefore, clear that it has been formed since the primary chalcocite was deposited. In both claims where native silver occurred, it was associated with malachite, which suggests that it came from tetrahedrite and it might just as well have been produced by the carbonated waters which deposited the calcite, as from any descending meteoric waters.

The King and Rainbow Veins.

The King vein is the largest one of a group of four, situated on the south side of Hunter basin at an elevation of about 6,000 feet, at a point where the topography is exceedingly rough and steep. The vein does not outcrop continuously throughout its length but there is a fairly good alignment of all the outcrops and workings and a rough continuity of strike which makes it probable that it is one vein.

The total length is about 1,000 feet. The profile of the vein, and the workings, are shown in Fig. 49, which represents a section through the center of the vein and parallel to the strike.

The width of the vein varies from 10 inches to 3 or 4 feet. The walls are sharply defined against the tuff country rock. In a few places a small amount of reddish hematite gouge was found along one or another of the walls. The walls stand nearly vertical, and the strike of the vein is at an angle of about 45 degrees to the strike of the bedding of the tuffs, which dip 18 degrees to the northeast.

The composition of the vein varies from place to place along its strike. At the farthest north pit the vein has a width of about 4 feet and consists almost entirely of banded quartz containing

small lenticular cavities and horses of the country rock. Pyrite in the form of small cubes and pyritohedrons is freely disseminated through the quartz. Associated with the pyrite is an equal amount of arsenopyrite. Replacing these minerals and the quartz, is a fairly large amount of chalcopyrite and zinc blende, which appear to have been deposited almost simultaneously.

The ore of the King claim may, for purposes of description, be divided into the chalcopyrite-pyrite ore of the east end, bornite-chalcopyrite ore of the central part, magnetite ore of the

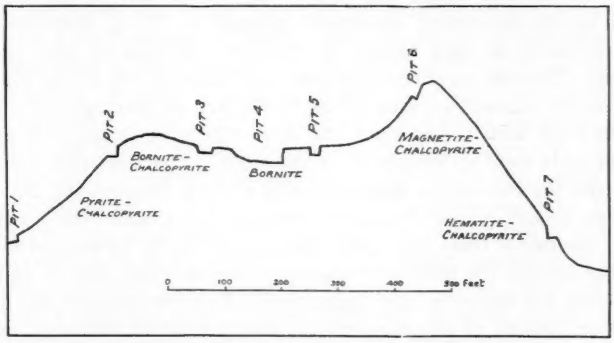

FIG. 49. Section parallel to King Vein.

middle south part, and the chalcopyrite-specularite ore of the western end (see Fig. 49).

The chalcopyrite-pyrite ore is the most plentiful of the four types, and is distinctly different in appearance and composition. It has a brassy color and is associated with a large amount of quartz. The pyrite grains are about one millimeter in diameter, fairly uniform in size, and rather evenly distributed in the quartz, but with a slight tendency to form bands. The arsenopyrite, the only arsenic-bearing mineral, occurs in grains of a similar size but is not so plentiful. The chalcopyrite is much more plentiful than the other minerals, forming about 70 per cent. of the sulphides present. It replaces the quartz extensively and also forms

numerous small veins in the pyrite. These veins become so large and numerous in some of the pyrite as to leave only small skeletons of the original grains. Associated with the chalcopyrite, and intergrown with it in a manner strikingly similar to the graphic structure, is a large amount of zinc blende. It replaces the gangue and pyrite, and appears in every way to have been deposited with the chalcopyrite. The common rule for the sequence of these two minerals is for the blende to slightly precede the chalcopyrite, but no evidence could be found to prove that rule in this ore.

The bornite-chalcopyrite ore of the central part of the vein is by far the richest, specimens collected by W. F. Robertson assayed 63 per cent. copper, 81 oz. silver, and 0.04 oz. gold per ton. The transition from the chalcopyrite-pyrite ore to the bornite ore cannot be traced owing to the lack of outcrops, but in the main shaft it was noted that there was more chalcopyrite at the ends than in the center of the shaft. The structures seen under the microscope showed mutual contacts between the chalcopyrite and bornite in most of the cases but towards the south of the tunnel there was some chalcopyrite which forms narrow rims around the bornite with many spikes pointing into it, and giving it a distinctly later appearance. This ore contains also a large amount of silver-bearing tetrahedrite which was seen as rounded or elongated masses with smooth even contacts in the bornite and chalcopyrite, but with a preference for the chalcopyrite, or the contacts of the bornite and chalcopyrite. It was never seen in veins and is undoubtedly primary, having come in with the copper sulphides or in places slightly later than them. Magnetite grains become common in the eastern part of the main trench. They contain small veinlets of hematite which never go beyond the edges of the magnetite, and many of them are sprinkled over with numerous specks of chalcopyrite which grade down in size to submicroscopic. A few of these grains were composed of bornite, and some of the larger ones were slightly altered to covellite. Tetrahedrite was also found. No hematite outside of the magnetite grains was seen in this ore excepting a very few scattered blades and rounded grains in the

quartz and other gangue. In some of the specimens there were some malachite and much limonite, indicating oxidation. Covellite is extensively developed along cracks in the bornite but is seldom seen in the chalcopyrite. The cracks in many cases proceed through the chalcopyrite but the solutions have produced no visible effect. This is an excellent example of selective replacement. Chalcocite is almost entirely absent from the King vein, and was seen in only one specimen, where it occurred along minute cracks in almost microscopically small amounts.

Magnetite ore begins to appear about 100 feet south of the main shaft, and the magnetite gradually increases in amount until, at the highest part of the ridge, the vein is almost solid magnetite, with a small amount of quartz. The magnetite is well crystallized when it occurs as small grains in the quartz, but the larger areas are irregular in outline and appear to replace the quartz. The smaller crystals are much more homogeneous than the large areas but contain small specks of chalcopyrite, bornite, and small veinlets of hematite, which are either confined to the crystal in which they occur, or to a narrow space along the margin. The larger areas of magnetite contain a great deal of hematite which appears to be of two generations. The larger amount is in the characteristic form of bundles or sheaves of narrow blades, often with a radiating habit. These blades are, however, extensively corroded, so that in the majority of cases there is nothing but a ragged skeleton left, with just enough hematite to suggest the original form. Besdies this, there is a considerable amount of hematite which occupies small veins cutting the magnetite, or surrounding it in the gangue contacts similar to the hematite in the small magnetite crystals. This is clearly later than the magnetite, and the hematite blades are just as clearly of an earlier date. All the magnetite is impregnated with chalcopyrite, bornite, tetrahedrite and probably some native silver, forming a structure which is remarkable if not unique. The sulphides are also disseminated in the gangue, but as larger grains. In both the gangue and the magnetite the copper minerals are slightly altered to covellite and secondary chalcopyrite and are replaced by limonite. Certain pseudomorphs of covellite, after bornite or chalcopyrite,

contained a perfectly developed lattice structure, in which the covellite formed the background. These alterations indicate that considerable surface oxidation has taken place in this ore and it is believed that these processes have produced that part of the hematite which is clearly a late component of the ore.

The evidence favoring secondary hematite is unusually clear in these ores. The hematite veinlets are fine and persistent, following cracks in the magnetite as well as the margins of the grains, and do not exist apart from the magnetite. The existence of secondary hematite is gravely doubted by many eminent geologists and the question is a prominent one in current discussion on secondary enrichment.

The hematite-chalcopyrite ore found at the southwest end of the vein consists of a large amount of chalcopyrite and specularite with small amounts of bornite, tetrahedrite and magnetite. The striking feature of this ore is the large amount of specularite which forms veins 2 or 3 inches in width. The chalcopyrite occurs in massive veins and contains many small irregular areas of bornite with a little tetrahedrite. The chalcopyrite replaces the hematite blades rather extensively, cutting into their sides and often dividing them into irregular fragments. The bornite is in an advanced stage of alteration to covellite and chalcopyrite, the latter mineral forming an exceedingly fine lattice structure in many of the bornite grains. The chalcopyrite is completely fresh. The tetrahedrite is not noticeably plentiful, and is inclined to be located near the bornite. It seems to be of an earlier period than much of the chalcopyrite. Limonite is plentiful in this ore and can be easily seen replacing the hematite and chalcopyrite, and in places, the magnetite. The chalcopyrite is only slightly attacked and for the most part is conspicuously fresh. This part of the vein is also surprisingly rich. Specimens of the pure chalcopyrite collected by Galloway,[1] of the British Columbia Bureau of Mines, assayed: gold, 0.08 oz.; silver, 87.5 oz.; copper, 32.8 per cent. A sample of magnetite associated with bornite from the same opening assayed: gold, 0.20 oz.; silver, 25 oz.: copper,

[1] Galloway, J. D., "Mineral Resources of a Porton of the Omineca Mining Division," British Columbia Bureau of Mines, Bull, 4, 1915, p. 53.

25 per cent. A sample across the vein which is about 2½ feet wide assayed: gold, 0.14 oz.; silver, 26.9 oz.; copper, 14.6 per cent.

No other gangue than quartz was found in any part of this vein.

The alteration of the country rock immediately adjoining the King vein is comparatively slight. The tuffs have lost their reddish color to some degree and have become somewhat greenish. In polished sections they are seen to consist of fine-grained tuffs which have become silicified and chloritized with the introduction of a small amount of epidote. The sulphides have been disseminated in the adjoining rock in places somewhat plentifully. The tuffs show their usual amount of very fine-grained hematite and also some magnetite. As one follows the vein southwest from the main shaft there is a notable increase in the amount of epidote of the country rock, which increases still more in amount west of the pinnacle where the magnetite ore occurs. This epidote is always associated with a large amount of very coarse-grained specularite. A similar increase in the amount of hematite and epidote is observed in passing southwest from the King shaft towards the Rainbow claim, and in this vicinity the concentration of these two minerals is quite remarkable. The tuffs are veined with them and numerous large spherical nodules are formed which usually have the hematite crystals assembled in their centers.

Closely associated with the King vein and located only 500 feet to the north is the Rainbow vein. It runs in a southwest direction towards the west showing of the King vein. This deposit consists of a network of small veins 2 or 3 inches in diameter, which run promiscuously about the ridge but which have a general trend in the direction of the south 45 degrees west and pointing towards the west showing of the King vein. In places the veins are confined to the joint plains and bedding.

These veins contain quartz, epidote, hematite, chalcopyrite, magnetite, zinc blende and a white mineral associated with the zinc blende believed to be a silver mineral.

The most plentiful mineral is the hematite which is in the form

of a very coarsely crystalline specularite and, besides occurring in the ore veins, is plentifully distributed through the country rocks for a considerable distance from the veins. Samples of it collected by Robertson[2] assayed: copper, 6.7 per cent.; silver, 36.8 oz.; gold, 0.88 oz.; and copper, 6.6 per cent.; silver, 58 oz.; gold, 1.68 oz. per ton. A number of specimens of this specularite were examined under the microscope, both the metallographic and the petrographic. The thin flakes which cleave off easily, when mounted in sealing wax and cleaned with a chamois, make excellent preparations for the reflecting microscope. All of these that were studied were found to be perfectly homogeneous under the oil-immersion lens. Polished sections were also examined and in a few, chalcopyrite was found interlaminated with the leaves of hematite, but only in minute quantities. The preparations studied under the petrographic microscope transmitted a brownish-red ray, showed no pleochroism, and a very weak double refraction. They also appeared perfectly homogeneous. In view of these facts it is very difficult to explain the presence of so much silver and gold, unless the samples taken by Mr. Robertson contained also a considerable amount of magnetite. Magnetite is almost as plentiful as hematite, and is associated with numerous specks of copper sulphides and silver minerals. The zinc blende is also a peculiar type, and occurs in flat lenses in the quartz associated with chalcopyrite. It is quite transparent when poilshed, but when taken from the vein is coated over with a thin black film, which, with its well-developed cleavage, gives it the appearance of hematite. The zinc blende is highly impregnated with chalcopyrite and the white mineral already referred to. The chalcopyrite is fresh and homogeneous and replaces the hematite and zinc blende. Bornite was seen in only one specimen and there in very small amounts.

Oxidation has produced a considerable amount of limonite and a little covellite.

These metallic minerals were associated with quartz and large quantities of epidote. The quartz has preceded hematite which

[2] Robertson, W. Fleet, Annual Report of the Minister of Mines, British Columbia, 1905, p. J–126.

		King.						Rainbow.
		Pit 1.	Pit 2.	Pit 3.	Pit 4.	Pit 5.	Pit 6.	
		East end					West showing	
First period	Primary	Quartz Pyrite Arsenopyrite Chalcopyrite Zinc blende Tetrahedrite	Quartz Pyrite Arsenopyrite Zinc blende Chalcopyrite Tetrahedrite	Quartz (small amount) Chalcopyrite Bornite Tetrahedrite	Quartz Chalcopyrite Bornite Tetrahedrite	Quartz Bornite Tetrahedrite Magnetite Chalcopyrite	Quartz Chalcopyrite Bornite Tetrahedrite	
	Secondary			Covellite Malachite	Covellite Malachite	Covellite Malachite	Covellite Malachite	
Rock alteration		*Chlorite* Epidote	*Chlorite* Epidote	*Chlorite* Epidote	*Chlorite* Epidote	*Chlorite* Epidote	*Chlorite* Epidote	
Second period	Primary				Quartz ? Hematite Magnetite	Quartz Hematite Magnetite Chalcopyrite	Quartz Epidote Hematite Magnetite Chalcopyrite	Quartz Epidote Hematite Magnetite Chalcopyrite Zinc blende Tetrahedrite
	Secondary				Hematite ? Limonite	Hematite Covellite Malachite Limonite	Hematite Covellite Malachite Limonite	Hematite Limonite Malachite Covellite
Rock alteration					Chlorite *Epidote*	Hematite *Epidote*	Chlorite *Epidote*	Chlorite *Epidote*

replaces it, but the epidote is associated with the hematite in a manner which suggests a nearly simultaneous deposition of both minerals.

The country rock consists of tuffs which, when not altered, are a bright red color. Near the vein they are highly epidotized and silicified, and impregnated with coarse hematite. This zone of intense epidotization surrounds the deposit for several hundred feet, extending over to the King vein in its western part.

Summary of the King and Rainbow Veins.—The significant facts brought out in the observations on these veins are:

1. The King vein has the typical structure, rock alteration, and mineral composition of the other veins surrounding the granodiorite stock, and thought to be genetically connected with it.

2. The Rainbow vein has all the characteristics of the other type of mineralization, such as the abundant development of chalcopyrite, hematite and epidote.

3. As the King vein approaches the Rainbow, and comes within the region which was effected by late mineralization, the minerals characteristic of this period begin to appear in increasing amounts in the King vein and are seen replacing the bornite and tetrahedrite of the earlier period. At the extreme west end where the two veins come almost together the earlier minerals are almost completely obliterated by the chalcopyrite and hematite of the later period.

These facts are in strict accord with the theory which explained similar conditions in the Excelsior and High Grade veins. That is, there were two periods of mineralization, one following the intrusion of the granodiorite stock which produced the bornite-chalcopyrite ore, and one following the intrusion of the Bulkley eruptives which developed the chalcopyrite-hematite ore. The Excelsior and High Grade veins were effected throughout by both periods of mineralization owing to the proximity of the dikes, while only part of the King vein is effected by the late mineralization.

NOTES ON THE POSSIBLE ORIGIN OF THE MAGNESITE NEAR VALLEY, WASHINGTON.

OLAF P. JENKINS.

Since the fall of 1916 great quantities of a peculiar crystalline variety of magnesite have been mined in Stevens County, about fifty miles north of Spokane, Washington.[1] The rock was formerly regarded as a kind of building stone, a marble, and unsuccessful attempts were made to utilize it as such. Its true composition as magnesium carbonate was first published in 1902 by Dr. Solon Shedd,[2] professor of geology at the State College of Washington, Pullman, Washington, but it is only recently that it has been regarded valuable as magnesite.

From a mineralogical and genetic standpoint this peculiar occurrence of magnesite is exceedingly interesting. At one quarry, in particular, are exposures which suggest the possible origin of the material. This is the so-called U. S. Marble Quarry. In this quarry and near it are beds of magnesite and of dolomite and "pseudo-serpentine,"[3] all apparently genetically affected by an intrusive rock, which is also exposed, especially at its contact with these beds. In this case, the "pseudo-serpentine," in particular, is in direct contact with the intrusive rock. This appears to be the case in other localities. In this quarry, as in all the other magnesite exposures, the magnesite is in beds, forming a part of a limestone and dolomite series of rocks, while invariably

[1] R. W. Stone, "Magnesite Deposits of Washington," *Eng. and Min. Jour.*, April 13, 1918.

[2] S. Shedd, "Building and Ornamental Stones of Washington," Wash. Geol. Surv., Vol. II., Pt. 1, Ann. Rept. for 1902.

S. Shedd, "Cement Materials and Industry in the State of Washington." Wash. Geol. Surv., Bul. No. 4, 1914.

[3] Clarke, F. W., "A Pseudo-serpentine from Stevens County, Washington," published in Shedd's building stone report, already referred to, and in U. S. Geol. Surv., Bul. 262, pp. 69–71, 1905, and in *Am. Journ. Sci.*, Vol. XV., May, 1903. In this paper the probable content of this "pseudo-serpentine" is given thus: Hydromagnesite, 5.0 per cent.; chlorite, 14.0; serpentine, 20.0; brucite, 60.0; and extraneous water, 1.0.

dike material, much like that referred to, occurs in the immediate neighborhood.

Under the microscope a thin section of the dike rock shows an abundance of brown hornblende, which has been largely altered to what appears to be chlorite and serpentine (hydrous magnesium silicates), and also feldspar, altered to such an extent that its identification is difficult, and magnetite which, in places, surrounds grains of pyrite in the rock, with the appearance of having altered from the pyrite. Other dikes in the vicinity are darker green in color and show even further alteration to serpentine and chlorite. None of these dike rocks when fresh, however, appear, to the unaided eye, to be altered, for they are firm and hard, but with the use of the microscope, extensive alteration (probably hydrothermal) can be detected.

In California, magnesite generally occurs as white, porcelain-like material in veins in serpentine, but in this Washington locality the magnesite is distinctly crystalline, very much like crystalline limestone. In some cases the crystals are as much as one and even one and a half inches in length, in others much less. Pink and light gray are two prominent colors of the magnesite, although in some cases it is white, while in others, nearly black. It is often quite difficult to distinguish, without analysis, which material is magnesite and which is dolomite or calcite. When the problem is worked out in some one special quarry the rest of the material in the immediate vicinity can, to a certain degree, be distinguished by simple physical examination.

In Red Marble Quarry, where the dolomite and magnesite are generally distinct, the magnesite portions appear to be replacements of the dolomite. In fact, the magnesite forms coarsely crystalline stringers and vein-like bodies in fine-grained dolomite, the veins lying in such close juxtaposition that, in the main body of the quarry, nothing but magnesite is found. The writer followed the horizon in which this occurred and found that here and there magnesite was present, the rest of the horizon being dolomite or limestone. It was difficult, however, to follow this horizon, without some detailed structural work and areal mapping. In fact, the limestone areas may represent lenticular

Red Marble Quarry. Exposure of solid magnesite. At the right are beds of dolomite and magnesite dipping to left. Photo by M. J. Gnagy.

Surface exposure near Red Marble Quarry. Coarsely crystalline pink magnesite has partly replaced white, fine-grained dolomite. Against the exposure lies a six-inch rule. Photo by M. J. Gnagy.

forms, in which case the structural features would be still more complicated to determine. The interesting fact is, however, that wherever the magnesite occurs, in the immediate neighborhood there are exposures of the dike rock.

In the U. S. Marble Quarry, where the dike is so well exposed,

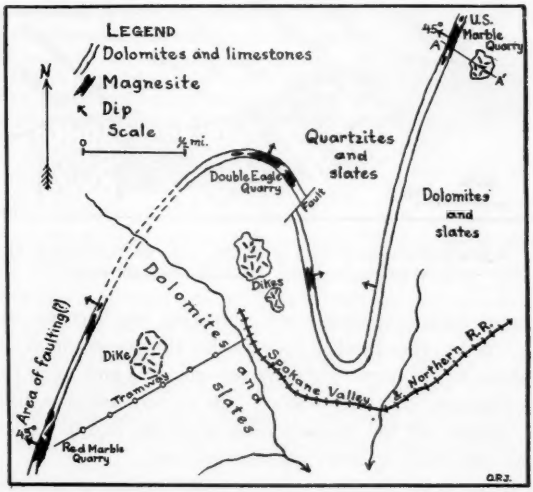

FIG. 50. Sketch map of a portion of the magnesite area west of Valley, Stevens County, Washington, showing bodies of magnesite replacing a dolomite bed, and their situation with respect to the dike rock.

a vertical exposure of the intrusive rock shows its direct effect upon the thin dolomitic beds it cuts. These beds are distorted and intercalated with yellowish-green "pseudo-serpentine." Farther away from the dike are more dolomite beds and magnesite.

Although as yet this problem has not been conclusively worked out, it seems probable that the presence of the intrusive dike rock has affected, through the aid of circulating underground water, the carbonate beds of the formation, causing them to pass through various changes, resulting in the formation of magnesium minerals, such as serpentine and chlorite, the hydrous

silicates, brucite, the hydroxide, and hydromagnesite and magnesite, the carbonates, all of which are present in this locality. It also appeared that where the "pseudo-serpentine" material (sometimes identified as ophicalcite[4]) was formed, the original

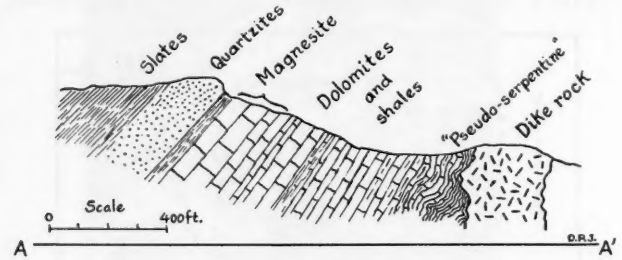

FIG. 51. Approximate cross-section along line *AA'*, on sketch map, showing relation of magnesite to dolomite and dike rock.

beds (now metamorphosed) are somewhat argillaceous or silicious. On the other hand, it appears that the magnesite areas are in horizons which were originally less silicious and more carbonate in character than the others. The writer, however, has not seen a contact of the igneous dike with the highly carbonate beds, but only with the more argillaceous ones.

The writer suggests the possibility that long before the present rocks were exposed at the surface through denudation, circulating underground waters, directly affected by the presence of the intrusive dike (composed largely of magnesium silicate minerals), provided the source from which the replacement of the dolomite or limestone beds by magnesite was effected or by which calcium was substituted for magnesium. Although the intrusive rock probably affected the surrounding rocks more or less at the time of its intrusion, by means of its radiation of heat and by its accompanying gases or mineralizers and ascending waters, the greater part of the metamorphism discussed here has probably taken place subsequent to the intrusion, for the reason that the dike shows alteration of similar nature to that of the surrounding beds.

[4] Foote Mineral Company collection.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

SILVER DEPOSITION AND ENRICHMENT AT COBALT, ONT.

Sir:—Under the title of "Significant Mineralogical Relations of the Silver Ores of Cobalt,"[1] Dr. E. S. Bastin gives the results of a microscopic study of the ores of this district, and in conclusion, after reviewing his own results together with the experimental data obtained by his colleague, Dr. Palmer, in chemical research along the same lines, he applies the theory of enrichment by descending surface solutions (commonly called "Secondary Enrichment") to account for the remarkable bonanzas of this camp.

I may say, that in certain minor points I am inclined to agree with Dr. Bastin, *i. e.*, the deposition of the silver by metasomatic replacement along minute fractures and cleavage planes, and in the application of the rhythmic precipitation hypothesis of Liesegang to explain the intricate interbanding of the cobalt and nickel minerals; with the major conclusion, however, as outlined above, I take issue, and believe that in doing so I am in agreement with most of those who have had an opportunity of studying the field relations of the ores in question. The author admits that he had never studied the Cobalt deposits in the field, if he had done so, I think he would have modified his views, as in my opinion, they are opposed to the field evidence concerning these ores which

[1] ECON. GEOL., April-May, 1917.

shows practically no points of congruence with that relating to secondary enrichment.

From personal invesigation of a number of copper and silver veins of Mexico and the southwestern United States, enriched more or less by descending solutions, combined with what I have gathered from reading the extensive literature devoted to this subject, I have noted that such deposits are characterized, first by a well-defined zone of oxidation above the enriched ores, and second by an equally distinct zone of primary or "protore" below the same, thus indicating a fairly evident connection with the surface.

At Cobalt both these zones are lacking, unoxidized ores are frequently found right at the surface, and in no case does oxidation persist over a few feet in depth; at the bottom of an ore-shoot all that is found is a small quantity of low grade smaltite and niccolite, which on further sinking quickly disappears, and is succeeded by barren calcite showing practically no mineralization whatever. The same condition found at the bottom persists all around the periphery of an ore-shoot, showing that in a vein the mineralization is local in character, and that protore, in the sense that it is understood by students of secondary enrichment, does not exist in these deposits.

It has been stated regarding the absence of the zone of oxidation, that this country has been heavily glaciated, the surface deposits all swept away, and what now remains are merely the roots of veins from which the upper parts have been removed; considering this point with reference to these deposits, I may say, that a well-known vein at Gowganda, which at the present time is a notable producer, is characterized by the following geological conditions: the diabase underlies the Keewatin at a low angle (about 30 degrees), the vein cuts across the contact, being found in both formations, a remarkable enrichment exists in the diabase, but above the contact, towards the surface, the vein becomes barren; according to the criteria of secondary enrichment, we would expect that the upper part should show some evidence of leaching and oxidation, by the appearance of erythrite or anna-

bergite, the pink and green cobalt and nickel arsenates, which are the commonly occurring oxidation products of this type of ore. From personal observation, however, I can say that such is not the case, the vein filling is merely calcite, showing absolutely no sign of oxidation, or other evidence of descending solutions.

In the Temiskaming mine, near Cobalt, several ore-shoots were developed in the Keewatin just above the upper contact of the intrusive sill. Subsequently a shaft 1,600 feet deep was sunk to prospect the lower contact, the diabase at that point proving to be 1,100 feet thick. Some silver was found below the lower contact. It seems difficult to understand how descending solutions could percolate such a great mass of rock, and only leave evidence of their existence on the upper and lower contacts, 1,100 feet apart.

Other instances could be given along the same lines, but the two cited above, in my opinion, give the clearest proof against enrichment by surface agencies.

When the theory of enrichment by descending surface solutions was first applied to these deposits by S. F. Emmons,[2] not sufficient work had been done to demonstrate the structural relations of the ores, and it seemed reasonable to consider them as being formed by processes analogous to these characteristic of somewhat similar deposits in other districts; since then as a result of extensive development, the balance of probabilities has been found to weigh heavily against this theory, and it has not been considered applicable, both by Miller and other geologists who have studied the field relations of the ores, and likewise by those concerned in their exploitation. I do not know of any scheme of exploration along lines suggested by the conclusions of Emmons and Dr. Bastin. From the operator's standpoint they lack the primary qualification of being workable.

The occurrence of ore-shoots in this district is governed by certain structural conditions, and the connection with surface agencies, either past or present, appears comparatively remote. In every case they have a very evident relation to intrusions of

[2] Bain, H. F., "Types of Ore Deposits."

Nipissing diabase, being found either in that rock or its vicinity, rarely over two hundred feet from the contact; when not in diabase they may occur in conglomerate, or Keewatin greenstones (the rocks usually invaded by the intrusive); in one case I saw a vein in granite, but in every instance, diabase is in the immediate neighborhood. Secondly, in addition to the main intrusive contact, they are related to other non-intrusive contacts in the adjoining formations, for instance, in the footwall of the sill, in the area occupied by the Nipissing, Coniagas, LaRose and other mines, the veins occur in conglomerate of the Cobalt series underlain by Keewatin greenstone, the veins tend to increase in richness with depth, up to the point where they enter the lower formation, then the values disappear; although the veins still persist, they become weak and broken up, the filling being only barren calcite.

East of the area just described, the veins are principally in the diabase intrusive, a short distance above the lower or footwall side of the sill, like the others, they usually improve with depth up to the contact with the underlying Keewatin, after which they show a marked flattening of dip (previously they were about vertical, as are most of the veins of this camp) attended by a falling off in values, although, possibly not as great as in the case of the conglomerate veins (there is little or no conglomerate in this locality).

At the Temiskaming Mine, about four miles southeast of Cobalt, the ore-shoots are in Keewatin, above the upper contact of the intrusive sill, in this case the ordinary relations are reversed, the ore bodies show enrichment in the Keewatin, and tend to become impoverished on entering the underlying diabase; it was mentioned above that a shaft pierced the sill, and some silver was found in Keewatin below the lower contact.

It may be mentioned that a number of "blind veins" have been found at Cobalt, which do not outcrop at the surface, their characteristics are similar to those above described, *i. e.*, they show a concentration of values in one formation, increasing towards the contact with an adjacent rock, and an impoverishment after crossing the same.

All the enriched areas show strong fracturing, in some cases the downward continuation of an ore-shoot is arrested or deflected by flat fractures approximately parallel to the contact.

In the opinion of the writer, the localization of ore-shoots in this district is due to compressive stresses, developed probably as a result of incipient folding, causing differential fracturing, which affected the several formations according to their relative susceptibilities.

In the case of a group composed of conglomerate, diabase, and Keewatin, the adjustment was effected by the fracturing of the more brittle conglomerate, while in the other tougher rocks, the strain relieved itself by slipping along lines of shearing, resulting in smaller, less well-defined openings, and hence not so well adapted for mineralization.

When only the diabase and Keewatin are concerned, usually the major fracturing and consequent mineralization are confined to the former, as the more schistose nature of the Keewatin renders it less amenable to such action, the latter is however somewhat variable in character, owing to the presence in certain parts of the series of comparatively massive members, so that when a favorable conjunction of circumstances arises, *i. e.*, the contact of a massive phase with the intrusive, fracturing takes place, and ore-shoots are developed in this ordinarily barren formation.

In general it may be said, that where the three formations occur together, the ore-shoots are confined to the conglomerate, owing to its highly fractured condition rendering it very permeable to solutions, the values however quickly disappear after crossing the contact.

In the case of the diabase and Keewatin only, the ore-shoots usually occur in the first-named rock, but show rather more persistency after crossing the contact.

The case of the Temiskaming Mine is unusual, as in this case the Keewatin is the ore-bearing formation, this is likely due to the cause above outlined, *i. e.*, the presence adjacent to the contact of a massive member of that series; in this connection I may say,

that Mr. A. D. Campbell of the O'Brien Mine has noted that when veins pass from the Nipissing diabase into a relatively massive member of the underlying series known as the "Keewatin diabase," the values are more persistent than when they enter the more schistose rocks of the same formation.

The determination of the nature of the solutions which enriched these deposits is perhaps the most difficult problem connected with their origin. From laboratory experiments only, one would be led to consider them as being acid, a conclusion, however, entirely incompatible with the facts as indicated above, which point unmistakably to a deep-seated, and probably magmatic source, with resulting alkaline character. In this connection, it is well to point out that in the occurrence of silver in this district, it is invariably associated with a carbonate gangue, and that while silver carbonate is relatively insoluble, yet with the exception of the sulphate, it is more soluble than any other

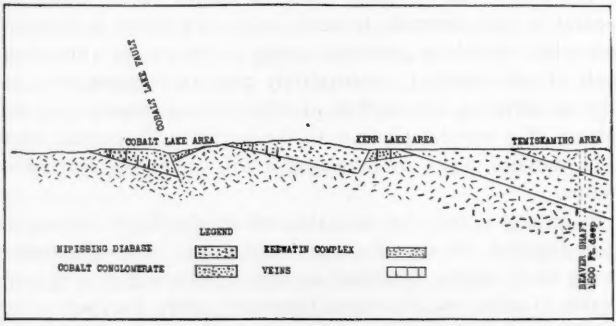

FIG. 52. Generalized section across the Cobalt District, adapted from Miller.

natural salt of that metal, and that furthermore, its solubility under moderate pressures is considerably increased by excess of carbon dioxide.[3]

Consideration of the foregoing facts points to the original

[3] Emmons, W. H., "Enrichment of Ore Deposits," Bull. 625, U. S. G. S., p. 257.

contention of Miller, that the silver was carried in carbonate solution, as offering the most reasonable explanation of the origin of these ores and most in line with conditions as observed on the ground, but on this point, however, little experimental data is available, and it is to be hoped for in the future, that some researches into the behavior of silver in alkaline solution may throw some light on this obscure subject.

Briefly summarizing the above data, the field relations of the ore-shoots point to the following conditions of formation: first, the mineralization of areas of local differential fracturing around the borders of the intrusive, the fracturing being caused by compressive stresses; second, that this mineralization is purely local

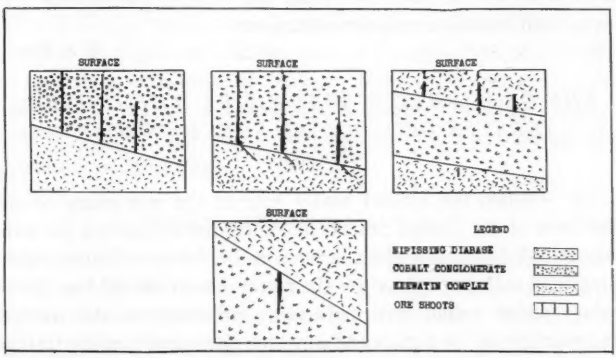

FIG. 53. Diagrammatic illustration of the relation of the enrichments to various contacts.

in character within the veins themselves depending on the relative permeability of the rocks they traverse; third, that the enriching soluions were deep seated in origin, being likely connected with the diabase magma, and consequently alkaline in reaction, and finally, that silver was probably carried in carbonate solution.

The evidence against descending solutions being the slight apparent relation of the ore bodies to the surface, either past or present, indicated by the absence of the zones of oxidation and of

primary or protore, two of the most important criteria for recognizing the action of such solutions.

In conclusion, I desire to express my appreciation to Messrs. J. G. Dickenson and A. D. Campbell, Manager and Engineer respectively of the O'Brien Mines, and to Mr. S. N. Graham, formerly in charge of operations at the Provincial and Peterson Lake Mines, for their many suggestions which I have incorporated in this article.

The appended diagrams, Figs. 52 and 53, show the relations of the ore deposits to the diabase intrusion, and other rocks of the locality; the first is a generalized section across the Cobalt District adapted from Miller, and the other is a diagrammatic illustration of the relation of the enrichments to various contacts, both intrusive and non-intrusive.

J. A. Reid.

THE GEOLOGIST IN WAR TIMES: THE UNITED STATES GEOLOGICAL SURVEY'S WAR WORK.

Sir:—When the United States entered the war many of the members of the United States Geological Survey joined the military establishment for direct service in the Army or Navy; others continued with renewed vigor the researches in the field and laboratory which would contribute most effectively to the welfare and warfare of the nation and in which they were already trained and experienced.

MILITARY SERVICE OF SURVEY MEMBERS.

Two hundred and sixteen members, representing all branches of the Survey organization, have responded by direct service in the military establishment. They are serving in many branches of the Army and Navy and are rendering service in all parts of the United States, including its insular possessions, such as the Virgin and Hawaiian islands, and in Europe.

The greatest contribution of men has been form the topographic branch, from which about 150 technically trained mem-

bers have joined the colors, and more than 100 of them have received commissions. Nearly half of these commissioned are now in Europe, applying their topographic training to artillery orientation and military mapping under war conditions. The remainder have been detailed by the War Department back to the Geological Survey to serve under essentially the same administration as before they entered the military service, and are making maps of areas selected by the War Department and collecting detailed information of military value for the exclusive use of the Army. About 50 other members of the Engineer Officers' Reserve Corps have been ordered to report to the Geological Survey for duty, in order to receive the special training in topographic surveying that will fit them for service overseas.

One of the Survey geologists in the Engineer Officers' Reserve Corps fills an important scientific post on General Pershing's staff that requires a knowledge of geology. One of the Survey topographic engineers was also assigned to General Pershing's staff, where he occupies a position that requires special knowledge of topographic engineering.

SERVICE AS AN ORGANIZATION.

The technical skill of the other members of the Geological Survey not in the military service is being utilized in work directly connected with the prosecution of the war. Almost immediately after the declaration of a state of war, practically all the Survey's work that was not connected with projects of immediate national value was stopped, and the trained investigators thus released took up war emergency tasks, each in his special field of work.

Several members of the Survey have contributed a large amount of their energies to the war service committees, being represented on the Military Committee and Committee of Geology and Geography of the National Research Council, the War Minerals Committee, and the Airplane Mapping Committee of the National Advisory Committee for Aeronautics.

Each of the branches of the Geological Survey has been called

on for technical information by military departments and commissions, so that the normal work of these branches has been greatly expanded to meet the increased demand for information.

GEOLOGIC BRANCH.

The geologic branch has been called on to furnish information dealing especially with the mineral resources not only of the United States, but also of foreign countries. The main questions regarding mineral deposits which arise in the conduct of the war, and which the geologist is best fitted to answer are: Where are the deposits? What are the conditions under which they occur? What has been the production from them? What are their resources? Many of the facts needed to answer these questions were supplied immediately from data that had already been collected by the Survey; others were promptly supplied from sources with which the Survey specialists were familiar through contact with the mining industry; still others were obtained by field examination and office or laboratory study. To meet the demand for a general statement that should afford a comprehensive review of the more essential minerals required by the industries of the country, a bulletin on "Our mineral supplies" was prepared, and within a week after the President had declared that a state of war existed, the first chapters of it were distributed.

Domestic deposits of many of the minerals for which the United States had been dependent on countries overseas were sought and found by the Survey's geologists—a result that will, to a greater or less extent, obviate the necessity of withdrawing ships from more direct military service in order to use them in bringing in minerals. The Survey may thus be considered an auxiliary of the Emergency Fleet Corporation. Among the domestic mineral deposits examined in the field, are ores of manganese, chromite, tungsten, quicksilver and sulphur. These examinations were in effect classified inventories of both our developed and our undeveloped reserves of these war necessities.

More than 1,500 letters a month are received by the Survey asking for information concerning the geology, or the location

and extent, of some mineral resource, and a reply to each of these letters is prepared by the appropriate specialist. Never before has the Survey been so active in bringing the producer and the consumer of mineral supplies into touch with each other and in keeping itself informed as to the constantly changing conditions in the numerous mineral industries.

The Survey has maintained close coöperation with other government bureaus, particularly with the Bureau of Mines. This naturally arose from the fact that these two bureaus occupy complementary fields of work, geology and technology. One of the closest connections was that made through the War Minerals Committee. This committee has utilized the information available from the various sources accessible to its members and has been instrumental in coördinating and furnishing information. The Geological Branch, and various parts of the Bureau of Mines have also coöperated in determining the distribution and the practicability of mining and treating some domestic ores formerly thought to be unadapted to commercial development, so that probably some shipping would thereby be released for more direct military service. At the request of the Secretary of Navy, the Survey and the Bureau of Mines have made a special field investigation of smokeless coals. The Survey has also coöperated with that bureau in an investigation of the sulphur resources of the country and is now undertaking a similar coöperative investigation of certain mineral deposits in the West Indies and Central America.

The geologic branch has furnished the War Department, on request, with reports on a field investigation of nitrate deposits in Guatemala, with laboratory chemical studies of the samples collected, a field investigation regarding certain camp sites, a field investigation of a rifle range, the road materials available near the battle front in France, on the enemy's mineral supplies, together with other reports on mineral resources. In connection with the establishment of training camps and aviation fields, several geologists are preparing descriptive texts to be printed on the backs of the Survey's topographic maps of such camps or

fields, and manuals covering military districts in the eastern United States, and will coöperate with certain state surveys in preparing descriptive geologic and geographic reports covering the several cantonments. The coöperative State reports were not undertaken in response to a direct request from the War Department, but were prepared to meet a probable need.

For the Navy, the geologic branch has selected, for leasing by the Navy Department, as a naval oil reserve, some of the most promising undeveloped oil lands remaining in the Osage Nation in Oklahoma; has made recommendations regarding suitable gas fields in West Virginia for the Navy's shell and armor-plate plant, has prepared a report on the distribution of coking coals; and in coöperation with the water resources branch has made investigations of the water supplies at many places.

For the Department of Commerce, the Survey specialist made a census of the available stocks and supplies of platinum.

For the Fuel Administration, and its predecessor, the Committee on Coal Production of the Council of National Defense, the collection of coal statistics was amplified, made more frequent, and generally speeded up. The specialist in charge of the Survey's coal statistics is directing this work.

At the request of the War Industries Board the geologic branch has furnished most of the required statistical data on mineral resources, and for this purpose it has collected much more complete statistics than were necessary before the war, and at more frequent intervals. The statistics including production, commitments, and stocks for most of the industrial metals are now collected weekly. Similar coöperation was established with the War Trade Board, Shipping Board, and other boards.

TOPOGRAPHIC BRANCH.

The topographic branch has contributed a large number of its members to the military service, and all its other members are connected with the work of making military maps of areas selected by the War Department. So great has been the call for topographic surveys along the borders of the country that even

though the Survey has stopped all work of this kind in the interior and has combed the country for trained topographers, it has been unable to get men enough for this technical work and has been conducting a school where closely supervised intensive instruction is given to promising candidates. By this means an effective field force has been maintained, even though over forty of the most skilled topographic engineers of the branch have gone to Europe and many more may soon go.

The topographic branch has also been actively preparing the bases for special route maps required for aviation and has compiled the data for three such maps, which have now been published. It has also been able to supply certain other government organizations with the instruments they needed to carry on their work. The War Department has recently turned over to the Survey the purchase and shipment of all instruments needed for topographic surveying, and this work is now being done by the topographic branch.

The topographic branch is also applying the adaptation of the camera to mapping, and the transformation of photographs to maps of the correct scale and orientation, and is perfecting the details of adapting such methods to mapping from airplanes.

WATER-RESOURCES BRANCH.

The water-resources branch of the Survey, in addition to performing its routine work, has been called on to furnish much special information that is immediately pertinent to the work of the War and Navy departments. In coöperation with the geologic branch, it furnished data concerning the camp-water supplies of all the border States except those contiguous to Canada; made tests of the water and estimates of the quantity available at the sites of war industries plants to be erected in the eastern part of the country; reported to the Surgeon-General's Office on the quality of the water at 33 cantonments in 23 states; determined the quantity and quality of the ground water available at seven aviation camps; made a field survey of the water conditions along the Mexican border west of Nogales, Ariz.; made comparison of

the quality of the water of European and American springs; made recommendations to solve the problem of contamination of the water supplies of Kansas River by sewage below Camp Funston; and reported on available water power and quality of boiler water at Yorktown, Va.

During the month of January, 1918, for example, advice was given in regard to the ground-water supplies for the encampment for army engineers near Accotink, Va., where a water supply of about 1,000,000 gallons a day is required; for the Langley aviation field, near Norfolk, Va.; and for a military establishment near Baltimore, Md., where 3,000,000 gallons a day is required and where some prospect drilling is in progress.

LAND-CLASSIFICATION BOARD.

In order that the mineral deposits or the agricultural lands still remaining in public ownership can be disposed of and so utilized in augmenting the mineral or the agricultural production of the country, it is necessary that the lands should be designated as appropriate for entry. The classification of these lands is part of the work of the land-classification board. The field work requires the location of the lands with reference to public monuments, the making of topographic maps by the plane table, the preparation of reports on the topography, soils, water supply, and vegetation, and of estimates of the density of the plant growth and of the stock-carrying capacity, or the water resources of the areas examined. It is estimated that under the provisions of the grazing homestead law alone, 40,000,000 acres of public lands must be classified before they can be utilized in increasing the meat supply of the country. The first step in this process is their appropriate classification. Of equal importance was the classification, in January, 1918, for instance, of 77,730 acres of land as naval petroleum reserves and of 132,024 acres as naval oil-shale reserves.

PUBLICATION BRANCH.

The call for information on geologic and geographic subjects has greatly increased the distribution of the Survey's maps and

reports for official use. The maps have been especially in demand for the expert use of the commissioned officers and for study by those who are in training as well as by the members of the various war boards who are planning nation-wide activities.

Many of the maps and other highly confidential data required in the military program have been prepared and printed in the Survey's engraving plant. Among the pieces of work already completed at the request of the War Department were the reprinting of maps of Belgium and parts of Germany, the publication of the Army index map, and numerous reproductions required by the General Staff, the Militia Bureau, the Adjutant-General's Office, the Chief of Engineers, the Chief of Ordnance, the Chief Signal Officer, and the Board of Ordnance and Fortifications. The cartographic specialist attached to the Survey's engraving division, who later joined the Signal Corps, designed and prepared specifications for a field lithographic press adapted to the needs of the Army. For the Navy Department many Admiralty charts have been reproduced, in one month more than 140,000 copies of maps were made, and during this year even more map-reproduction work for that department is to be done.

In the section of texts, practically the only reports that have been pushed rapidly to publication have been those dealing with needed mineral supplies. In addition, however, a translation was made, in coöperation with other branches of the Survey, of an important French technical report, "Manual for the artillery orientation officer," which was prepared and distributed for the use of the Survey's topographic engineers assigned abroad or being trained for such assignment.

PHILIP S. SMITH.

REVIEWS.

The Geology and Ore Deposits of Ely, Nevada. By ARTHUR C. SPENCER, Professional paper 96, U. S. Geological Survey, 1917; 109 pp., 15 plates, including topographic and geologic maps of Ely quadrangle, and 4 figures.

The recent professional paper on the Geology and Ore Deposits of Ely, Nevada, as noted by Mr. Ransome in the preface, is noteworthy as the first report issued by the U. S. Geological Survey to describe fully one of the great deposits of secondarily enriched, disseminated copper ore, commonly called "porphyry deposits."

Following an excellent custom, which, however, has not been at all abused by the Survey, the report opens with an outline or summary, which is explicit and complete.

In the description of the regional geography and geology (with which as usual the report proper commences), of most significance is the description of the Quaternary deposits and the discussion, based on a detailed study of the deposits, of the climatic changes since the beginning of the Quaternary. It is concluded that the great alluvial cones, the oldest of the Quaternary deposits, were formed during an epoch more arid than the present, but were dissected during more humid epochs, with, however, arid interruptions, which are indicated by well-marked terraces. This succession of humid and arid epochs is correlated with that worked out by Gilbert and Russell, during which the Bonneville and Lahontan basins were flooded and dissected.

The older and more important of the two series of igneous rocks of the district consists of deep-seated intrusives, porphyritic monzonites, which are greatly altered in most places, and which are the "porphyry" of the ore deposits. Unlike Lawson,[1] Spencer refers all of the deep-seated intrusives, altered and unaltered alike, to the same epoch of igneous activity, probably at the close of Jurassic time. His conclusion seems justified by the comparatively slight variation in the original character of the porphyry, by its structural relations, and by the acceptable explanation of its restricted alteration by the mineralizing solutions, which, as they have been shown to do in so many places, became active soon after the crystallization of the upper, now exposed portions of the intrusives.

[1] Lawson, A. C., "The Copper Deposits of the Robinson Mining District, Nevada," California Univ. Dept. Geology, Bull., Vol. 4, p. 350, 1906.

The structure is complicated but not more so than in other Basin ranges. The porphyry has been intruded, as cross-cutting bodies with steep walls, chiefly along an east and west zone, transverse to the general northwest trend of the intruded rocks. North of the principal zone of intrusion, the porphyry is nearly conformable with the folded sediments, and hence forms sills.

The discussion of the alteration or metamorphism of the rocks is in many respects the most important section of the report, as is indicated by its comparative length, 42 pages, whereas the section on the ore deposits is only 38 pages, and of these 7 pages are devoted to the history and production of the district. The discussion is carried on under two headings, igneous metamorphism and atmospheric metamorphism. Under the former are treated all those alterations which attended and followed the intrusion of the porphyry and which affected both invaded sediments and intrusives. Under the latter are considered all those changes accomplished near the surface by weathering and by descending rain water. The formation of the primary mineral deposits is of course one phase of igneous metamorphism, whereas the formation of the enriched copper deposits is the result of atmospheric metamorphism.

The changes produced by igneous metamorphism are, except for the marmorization of the limestone, restricted to the cross-cutting porphyry masses of the principal zone of intrusion, or to their immediate vicinity. Of the invaded rocks, limestones and shales, the former as usual have experienced the greater change, chiefly (1) marmorization; (2) silicification, resulting in jasperoids; (3) the development of lime-bearing silicate minerals; and (4) the formation of bodies of pyrite and of pyrite and magnetite. The metallic minerals are not confined to the bodies of pyrite or of pyrite and magnetite, but are estimated to comprise from 5 to 10 per cent. of a very great bulk of the altered rocks including the altered shales.

The alteration of the porphyry is similar to that accompanying the formation of mineral deposits at moderate to considerable depths in granitic rocks. The hornblende, plagioclase, and magnetite of the porphyry are progressively replaced by sericite, biotite, pyrite and chalcopyrite, and calcite. Portions of the porphyry, ordinarily those which were greatly fractured before metamorphism, are in addition seamed with veinlets of quartz and sulphides or with films of pyrite. As is common,[2] there is no evidence of a general change in the volume of the altered rock, the marked loss of aluminia, iron, lime, and soda, and slight loss of magnesia being compensated by marked gains of potash, sulphur, copper, and, where quartz has been deposited in fractures, of silica; and a slight gain of carbon dioxide.

[2] Lindgren, Waldemar, "The Nature of Replacement," ECON. GEOL., Vol. 7, 1912, pp. 521–535.

The character of the metamorphizing solutions and the physical conditions under which they acted is treated at some length, 12 pages, for the most part convincingly. The author argues that not only are the exposed porphyry masses altered, but that they are of insufficient size to warrant regarding them as the source of the solutions, or even of the necessary heat involved. Furthermore, it appears from the absence of metamorphism adjacent to the large apophysal masses that the quickly cooled portion of the intrusive magma, now exposed, was not rich in eliminable constituents. Hence it seems quite certain that the solutions rose from deeper and at the time unsolidified portions of the magma through the upper solidified portions. It is suggested, however, that at least locally, metamorphism may have begun before all the orthoclase and quartz of the now exposed porphyry had completely solidified, although little or no mention is made of distinct metamorphic stages. Attention is called to the fact that the solutions first released were above the critical temperature of pure water and hence the author argues they were gaseous. However, as the author recognizes, the constituents escaping were mutually dissolved, and the mutual solution would have a much higher critical temperature than pure water. Nevertheless, the ineffectiveness of the solutions first escaping might well be due to their gaseous nature, and consequent inability to carry a large load of nonvolatile matter.[3] But as is evidenced by the fact that the fluid inclusions in the cavities of many of the quartz grains of the altered rock occupy not more than 90 per cent. and not less than 75 per cent. of the space in any cavity, the solutions causing most of the metamorphism were somewhere between 200° and 350° C. and hence were in a liquid state.

Although the idea has undoubtedly been implied and even indirectly expressed by many economic geologists and has been directly expressed by some,[4] Spencer's report is one of the first to state clearly that not only did the composition and solutions continually change by reaction with the rock which the solutions traversed but that the solutions may have originally been acid, becoming alkaline by reaction chiefly with the sodium of the wall rocks. The principal dissolved substances in the original solutions appear to have been SiO_2, H_2S, KSH, HCO_3, F, Fe, and Cu, with probably a great excess of CO_2. The author points out that whereas originally alkaline solutions would affect the observed meta-

[3] Johnson and Niggli, *Jour. Geol.*, Vol. 21, 1913, state that in general there is a very marked falling off in solubility just below the critical point; although they state further that this fact in itself is no reason why at still higher temperatures and pressures the dissolving power of gases should not again increase.

[4] Sales, R. H., "Ore Deposits at Butte, Mont.," *Trans. Am. Inst. Min. Eng.*, Vol. 46, 1914, pp. 81–93.

morphism and metallization of the porphyry, precipitation being brought about by a decrease of dissolving power, owing to loss of temperature and to loss of alkalinity, in consequence of the precipitation of potassium as orthoclase and sericite, yet where replacement of the limestone to form jasperoid took place, the original solutions should have become even more alkaline by the solution of the $CaCO_3$, hence an adequate cause of precipitation would be wanting since increasing alkalinity would more than offset the decrease in temperature. Nevertheless it is indicated, the possibility of colloidal solutions being properly ruled out, that it would not be possible for acid solutions to hold copper sulphides in large amounts of strongly concentrated form, owing to the suppression of the sulphide ion in the presence of free acid (or of hydrogen ions), owing to the reaction $S'' + H' = SH'$. Hence solutions originally acid would finally become saturated with sulphide minerals only through decreases in temperature and acidity.

The rate of the cooling of the solutions being greater during the first stages of metamorphism, before the rocks which the solutions traversed were heated to the temperature of the solutions, than at any time afterwards, it is reasoned that the solutions would be most effective during the early stages. It is further suggested that the reactions were of such kind as to absorb heat, thus still further aiding the precipitation of the minerals. The problem of determining the heat of solution of various silicate minerals is suggested, so that the energy changes of metamorphism could be calculated. The idea that metamorphic reactions absorb rather than liberate heat is held partly because it appears to be author that if metamorphism resulted in a rise of temperature, the process would be self-perpetuating, whereas it is generally held that contributions of energy from outside are necessary. The author's conclusions do not seem to be entirely justified. One hardly doubts that the formation of garnet, tourmaline, and other high-temperature minerals takes place only through the absorption of heat, but on the other hand it seems probable that the breaking down of such minerals of complex composition into carbonates, kaolin, and silica, doubtless liberates heat, since it would obviously require heat to reconstruct the products of decomposition into their original state. Whether the discussed replacement of calcite, by quartz, liberates or absorbs heat cannot of course be argued from their occurrence, since the replacement appears to have taken place under different physical conditions.

The zonal arrangement of the minerals, notably the absence of lead and zinc sulphides in the medial zone, the greater association of gold and silver with lead and zinc, and the order of deposition of the various minerals, which nearly corresponds to the order of their abundance within the district, leads to the suggestion that the order of crystalliza-

tion was due to the relative concentration of the metallic radicals in the mineralizing solutions, except that molybdenite was deposited within the medial zone and thus before the more abundant galena. Furthermore sphalerite, although less abundant than galena, was deposited with it. Hence the order of increasing solubility of the several sulphide minerals is deduced as molybdenite, sphalerite, galena, chalcopyrite, and pyrite. The absence of lead and zinc, which would be expected to form during the late states of metallization, in the medial zone, is concluded to be due to a sudden change in the character of the solutions toward the close of metallization, a change believed to have had its origin within the magma. The deposition of the pyrite films in portions of the metamorphosed porphyry is considered to be another expression of the same change. Thus the process of metallization appears to have occupied a definite and rather short interval of time; a conclusion which has impressed itself on many geologists, from observations elsewhere.

The metamorphism due to atmospheric agents consists of weathering and concentration, the latter being largely secondary copper deposition. The weathering of the primary deposits, not at all unusual, is clearly and concisely described. The most prominent feature is the characteristic formation of gossan from the oxidation of pyrite, in places accompanied by oxidized copper minerals. The weathering of the mineralized porphyry, which is of most significance, indicates a loss of all the constituents except, of course, water, a loss indicated by the increased porosity of the weathered rocks and the solution of the metallic sulphides. Otherwise the mineral changes do not seem to have been great, although there has been an insignificant formation of kaolin.

The chalcocite enrichment, already described in this journal, Vol. 8, 1913, pp. 621–652, is on the other hand treated in great detail, in over 15 pages, the climatic conditions favorable to most pronounced enrichment being given particular emphasis. After a discussion of the general chemistry of chalcocite enrichment, as determined by recent experiments, many having been performed by the author, he shows by an ingenious argument that the amount of oxygen carried downward into the ore body by rain water would be entirely inadequate to account for the amount of oxidation necessary within any reasonable time. Hence he concludes that the oxygen must have been derived directly from the air in the upper porous capping.

In the discussion, the reactions are divided into three groups, assignable in a general way to upper, intermediate, and lower portions of the body of sulphide-containing material. In the upper portion or zone, atmospheric oxygen is the oxidizing agent; in the intermediate zone, ferric sulphate; and in the lower zone, cupric sulphate. The reactions in the first two zones are similar, chalcocite is first attacked, and the decomposi-

tion of chalcocite, pyrite, and chalcopyrite tends to form sulphuric acid and cupric sulphate, ferric sulphate forming of course only in the uppermost zone where free atmospheric oxygen is available. In the lower zone cupric sulphate is reduced to chalcocite, thus oxidizing the iron of the pyrite and chalcopyrite to ferric sulphate, and forming also sulphuric acid. As is suggested by laboratory experiments and by studies of polished specimens, chalcocite is not immediately precipitated, but is preceded by the formation in succession of the various members of the pyrite-chalcopyrite-chalcocite series.

The greater susceptibility of chalcopyrite over pyrite to replacement by chalcocite, noted at Ely and commonly elsewhere, is convincingly explained in part by the fact that the transition of chalcopyrite to chalcocite involves theoretically a contraction of from 6 to 15 per cent., whereas the transition from pyrite to chalcocite involves an expansion of from 54 to 75 per cent. Furthermore it appears as if pyrite was significantly replaced only where it was subject to attack by some other reagent than cupric sulphate, probably ferric sulphate. An analysis of the mine water shows that it possesses but secondary salinity and alkalinity, and hence, as is commonly believed, chalcocite was probably not deposited from strongly acid solutions.

The relation between the water table and chalcocite deposition is carefully considered and it is noted that, although in general the chalcocitized porphyry lies above the water table, it continues downward, possibly to the lowest levels to which the water table descended during the most arid stages of at least the Quaternary period. On the other hand, it is obvious that the enriched porphyry has been partly to completely flooded during the humid epochs of the Quaternary and presumably of the Pliocene epoch as well. This is evidenced by the occurrence of iron-copper sinter near some of the mines, formed evidently at a time when the water table cut the enriched ore body. Furthermore local layers of ore, more enriched than the average, were probably formed during stages of high water level, when the remaining copper, incompletely precipitated during the short journey from the top of the ore body to the water table, was completely precipitated at the water level.

Obviously oxidation and enrichment began with the first exposure of the mineralized porphyry to oxidizing solutions and since then hundreds and possibly thousands of feet have been eroded, although the erosion was interrupted during the period when the volcanic rocks of probable Pliocene age were extruded and eroded. As there has been no lowering of the surface since the epoch during which the great alluvial cones were built up, it is clear that all of the secondary copper in the present ore bodies was deposited below the present surface since the beginning of the Quaternary. However, redistribution has been going on and the tops of the ore bodies have been gradually falling lower and lower.

The section on the ore deposits is introduced by a thorough and interesting review of the history of mining in the district. By far the most important of the ore deposits is the low-grade "porphyry" or disseminated copper ore, of which 95,000,000 tons had been developed in 1913. It occurs chiefly in the altered porphyry masses of the central intrusive zone, although some occurs in the closely associated jasperoids. Deposits of higher grade copper ore and ore bodies valuable for gold, lead, and silver also occur. As is customary in the "Survey" reports the occurrence and association of the principal minerals of the deposits are individually described. Nothing very startling is disclosed, except that crystalline kaolinite is entirely absent and that kaolin, as already mentioned, has been developed only in very small amounts by the weathering of the sericitized and mineralized porphyry.

Although none of the primary deposits have been found to be of commercial value, the deposits are classified according to certain features of primary origin, notably valuable metals, form and size, and mineralogic and lithologic character. As all the deposits appear to have been formed at the same time and under similar conditions, this classification affords a more detailed grouping and description than a purely genetic classification.

The classification is as follows:

Copper deposits; ores only where copper has been added to primary materials.
  Great-mass replacement deposits.
    Pyritized porphyry masses and their secondary copper ores.
    Copper-bearing jasperoid masses.
    Partly silicified limestone masses carrying copper minerals.
    Copper-bearing garnet rock.
    Copper minerals in metamorphosed shales.
  Minor-mass deposits.
    Replacement deposits.
      Irregular replacement bodies carrying sulphides and magnetite.
      Irregular replacement bodies composed mainly of pyrite.
      Pyritic replacement veins.
      Pyritic bed deposits.
      Copper ores associated with kaolin.
    Quartz veins carrying pyrite and chalcopyrite.
Silver-gold deposits; primary materials usually lean; enrichment by abstraction.
  Replacement deposits.
    Deposits of irregular form.
    Vein-like replacement lodes.
    Bed deposits.
  Fissure veins carrying precious metals.

The terms "Great-mass deposits" and "Minor-mass deposits" have been invented to designate respectively large bodies of disseminated ore minerals and smaller bodies more compactly segregated.

The "Great-mass deposits" consist of the metamorphosed rocks charged with from 2 to 10 per cent. of metallic minerals, chiefly pyrite with minor amounts of chalcopyrite. The enriched porphyry masses, that furnish the bulk of the ore, contain about .5 per cent. of copper, chalcopyrite having been greater in the veinlets than in the body of the rock. The enriched ore bodies lie beneath the usual capping of gossan and grade downward to mineralized porphyry too low grade to be worked profitably. They are, like other similar ore bodies, of blanket form and are extremely irregular, being dependent upon topography and weathering. In general the transverse cross-sections of the ore bodies are V-shaped, although in detail the lower surface exhibits greater relief than the upper. On a whole the deposits average from 150 to 250 feet in thickness, although in places in the sags they are from 100 to 250 feet thicker. The capping varies from 20 to 275 feet in thickness with an average of about 150 feet, except in the Ruth ore bodies, where it is from 270 to 435 feet thick. The capping is almost free from copper minerals, but in places there are large masses carrying from 1 to 2 per cent. of copper. In general the upper 70 feet averages about 0.3 per cent. of copper and the lower 43 feet, 1.1 per cent.

There are no workable, enriched deposits in the typical jasperoids. either because they contained too small an amount of primary copper or because drainage conditions were unfavorable. However, at one place in the Veteran mine there is a deposit of mingled jasperoid and porphyry. It is similar to the porphyry ores, although the jasperoid contains no orthoclase and does contain a little pyrrhotite. The grade of the ore is also a little higher, about 3 per cent. The partly silicified limestone is as heavily mineralized as the jasperoids and garnetized limestones, and appears to have contained as much primary copper. However, the enriched ore bodies are small and very irregular, occurring only in the pits of the karst-like topography into which, beneath the oxidized capping, the limestone is eroded owing to the localization of descending underground water to fractures in the limestone. Furthermore the secondary ore minerals are chiefly malachite and brochantite. The garnet rocks do not occur in as large masses as those described above but they carry a somewhat larger amount of primary chalcopyrite, 5 to 6 per cent. However, the deposits are too irregular to be reliable, and they have not been greatly enriched. The pyritized shale, on the other hand, contains but little primary copper, and little or no enriched copper.

The "Minor-mass" replacement deposits are composed largely of pyrite, although at three localities bodies composed of both magnetite and pyrite are known. They occur chiefly as replacements of metamorphic limestone, and many of them occur without the zone of most

intense metamorphism. Most of the deposits are irregular, but some of them are fairly regular, following fractures or favorable beds. Most of the deposits do not furnish ore, but the enriched pyritic replacement veins have furnished some high-grade copper ore from very shallow workings. One peculiar type consists of high-grade, compact bodies of oxidized copper minerals and native copper with kaolin, and appears to be the result of the weathering of sericitic and pyritic limestone.

The silver-gold deposits, with pyrite and galena as the principal primary metallic minerals, are found outside the zone of intense metamorphism. They are largely replacement bodies developed between limestone and shale, so that in form and origin they are similar to the "Minor-mass" replacement copper deposits. Only the oxidized portions of these deposits are valuable.

The last fifty pages of the report are devoted to the usual detailed description of the mines.

Many of the features described in the report are of general application, not only with regard to other and very similar deposits of disseminated ore, but to all ore deposits connected with intrusive rocks. Several of these features have already been mentioned. Perhaps the most important are: the greater amount of metamorphism in connection with cross-cutting stocks than with injected and conformable igneous rock bodies; the alteration of the stocks themselves by the mineralizing solutions; the zonal arrangement of the different minerals; and the changes due to weathering and enrichment.

One wishes that in places in the report the author had clearly stated his own conclusions to the problems and suggestions he arouses in the reader's mind, instead of allowing the reader to read between the lines, doubtless misinterpreting some of the facts and discussions. Since the primary mineralization is so clearly related to the changes that took place during the crystallization of the intrusive monzonite magma, more space given to the discussion of the crystallization and differentiation of the magma would be desirable. Such a discussion may seem to be out of place in a report dealing primarily with the geology of an ore deposit, but many mining engineers and not a few strictly mining geologists are unfamiliar with the later ideas with regard to the crystallization and differentiation of magmas. Hence they fail to appreciate the help which these recent ideas afford the mining geologist in reaching a satisfactory conclusion with regard to the genesis of ores, an increasingly important problem in the commercial exploitation of ore deposits. A great deal of the purely petrologic literature is never seen by mining engineers and geologists, hence those writing for the publications of the Geological Survey, which are very generally read and studied, should not neglect to deal with the broader problems connected with mining geology.

Some of the terms and phrases in this report are somewhat forced or obscure, as for example the use on page 16 of the phrase "of considerable individual continuity" in describing faults of great length. Although the undefined term "metathesis" is used in a portion of the report to be read only by technically trained readers, nevertheless the reviewer must confess that the exact meaning of the term bothered him and still does. The report is characterized by rather numerous summaries of descriptions and arguments previously made or to be later enlarged. Although adding somewhat to the bulkiness of the report this has added greatly to the average reader's convenience. Portions of the report, such as the section on ore deposits, are written in a more simple and explanatory style and deal with less involved and less theoretical problems than others. The reviewer has failed if he has not given the impression that the report is an excellent description of one of our most important types of copper deposits, and presents in a convincing manner most original arguments and ideas.

C. H. CLAPP.

SCIENTIFIC NOTES AND NEWS.[1]

RALPH ARNOLD has been appointed as a member of the Board of Tax Reviewers in connection with the administration of the War Revenue Act.

A. C. LAWSON, professor of geology in the University of California, was recently at Bingham, Utah.

R. A. F. PENROSE succeeds Eugene Meyer on the directorate of the Utah Copper Company.

ALBERT BURCH is in charge of investigations into the production of chromite for the U. S. Bureau of Mines.

THE Massachusetts Institute of Technology has granted leave of absence to F. H. Lahee, associate professor of geology.

WILBUR A. NELSON has been appointed State Geologist of Tennessee.

FRANCIS M. VAN TUYL, assistant professor of geology and mineralogy in the Colorado School of Mines, has been promoted to an associate professorship.

G. MONTAGUE BUTLER, E.M., Colorado School of Mines, has been appointed director of the Arizona State Bureau of Mines to fill the vacancy created by the resignation of C. F. Willis. He will continue to serve as dean of the College of Mines and Engineering. The new director of the bureau will emphasize geolog-

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

ical investigations, and will soon begin to collect data required for the preparation of a reconnaissance geological map of Arizona.

WILLIAM F. PROUTY, professor of geology in the University of Alabama, will complete field work, early this summer, for a map and report on Clay County, Alabama. This area contains the most productive flake graphite and pyrite mines of the State.

CHARLES T. KIRK has resigned from the positions of professor of geology in the University and the state geologist of New Mexico, to begin consulting practice in geology, with offices in Tulsa and Oklahoma City, Oklahoma.

J. F. KEMP has left Tulsa, Oklahoma, to resume permanent residence in New York.

KIRTLEY F. MATHER has resigned from his position at Queens University, Kingston, Ontario, to accept an appointment as professor of geology at Denison University, Granville, Ohio.

F. L. RANSOME, of the U. S. Geological Survey, attended the hearing before the U. S. Tariff Commission in San Francisco.

AS THIS NUMBER goes to press, we have received notification of Professor Irving's death, in France.

Professor Irving has been editor of this journal since its inception, and his loss will be deeply felt by all those who were interested in economic geology.